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C. A. Ellington

PRESIDENT

THE INSTITUTION

OF

MECHANICAL ENGINEERS

ESTABLISHED 1847.

PROCEEDINGS.

PUBLISHED BY THE INSTITUTION,
Storey's Gate, St. James's Park, London, S.W.

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1911.

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The Institution of Mechanical Engineers.

PAST-PRESIDENTS.

George Stephenson, 1847-48. (*Deceased* 1848.)

Robert Stephenson, F.R.S., 1849-53. (*Deceased* 1859.)

Sir William Fairbairn, Bart., LL.D., F.R.S., 1854-55. (*Deceased* 1874.)

Sir Joseph Whitworth, Bart., D.C.L., LL.D., F.R.S., 1856-57, 1866. (*Deceased* 1887.)

John Penn, F.R.S., 1858-59, 1867-68. (*Deceased* 1878.)

James Kennedy, 1860. (*Deceased* 1886.)

The Right Hon. Lord Armstrong, C.B., D.C.L., LL.D., F.R.S., 1861-62, 1869. (*Deceased* 1900.)

Robert Napier, 1863-65. (*Deceased* 1876.)

John Ramsbottom, 1870-71. (*Deceased* 1897.)

Sir William Siemens, D.C.L., LL.D., F.R.S., 1872-73. (*Deceased* 1883.)

Sir Frederick J. Bramwell, Bart., D.C.L., LL.D., F.R.S., 1874-75. (*Deceased* 1903.)

Thomas Hawksley, F.R.S., 1876-77. (*Deceased* 1893.)

John Robinson, 1878-79. (*Deceased* 1902.)

Edward A. Cowper, 1880-81. (*Deceased* 1893.)

Percy G. B. Westmacott, 1882-83.

Sir Lowthian Bell, Bart., LL.D., F.R.S., 1884. (*Deceased* 1904.)

Jeremiah Head, 1885-86. (*Deceased* 1899.)

Sir Edward H. Carbutt, Bart., 1887-88. (*Deceased* 1905.)

Charles Cochrane, 1889. (*Deceased* 1898.)

Joseph Tomlinson, 1890-91. (*Deceased* 1894.)

Sir William Anderson, K.C.B., D.C.L., F.R.S., 1892-93. (*Deceased* 1898.)

Sir Alexander B. W. Kennedy, LL.D., F.R.S., 1894-95.

E. Windsor Richards, 1896-97.

Samuel Waite Johnson, 1898.

Sir William H. White, K.C.B., LL.D., D.Sc., F.R.S., 1899-1900.

William H. Maw, LL.D., 1901-02.

J. Hartley Wicksteed, 1903-04.

Edward P. Martin, 1905-06. (*Deceased* 1910.)

T. Hurry Riches, 1907-08.

John A. F. Aspinall, 1909-10.

The Institution of Mechanical Engineers.

OFFICERS.

1911.

PRESIDENT.

Edward B. Ellington,	London.

PAST-PRESIDENTS.

John A. F. Aspinall,	Manchester.
Samuel Waite Johnson,	Nottingham.
Sir Alexander B. W. Kennedy, LL.D., F.R.S.,	London.
William H. Maw, LL.D.,	London.
E. Windsor Richards,	Caerleon.
T. Hurry Riches,	Cardiff.
Percy G. B. Westmacott,	Ascot.
Sir William H. White, K.C.B., LL.D., D.Sc., F.R.S.,	London.
J. Hartley Wicksteed,	Leeds.

VICE-PRESIDENTS.

Henry Davey,	Ewell.
H. F. Donaldson, C.B.,	Woolwich.
Arthur Keen,	Birmingham.
Sir William T. Lewis, Bart., K.C.V.O.,	Aberdare.
Michael Longridge,	Manchester.
A. T. Tannett-Walker,	Leeds.

MEMBERS OF COUNCIL.

William H. Allen,	Bedford.
Archibald Barr, D.Sc.,	Glasgow.
Sir J. Wolfe Barry, K.C.B., LL.D., F.R.S.,	London.
George J. Churchward,	Swindon.
Dugald Clerk, F.R.S.,	London.
Sir Robert A. Hadfield, D.Met., F.R.S.,	Sheffield.
H. S. Hele-Shaw, LL.D., F.R.S.,	London.
Edward Hopkinson, D.Sc.,	Manchester.
J. Rossiter Hoyle,	Sheffield.
George Hughes,	Horwich.
Henry A. Ivatt,	Doncaster.
Henry Lea,	Birmingham.
Robert Matthews,	Manchester.
Engineer Vice-Admiral Sir Henry J. Oram, K.C.B.,	London.
William H. Patchell,	London.
Walter Pitt,	Bath.
Thomas P. Reay,	Leeds.
Mark H. Robinson,	London.
Captain H. Riall Sankey, R.E., ret.,	London.
Professor W. Cawthorne Unwin, LL.D., F.R.S.,	London.
Wilson Worsdell,	Ascot.

HON. TREASURER.

Arthur Huson.

AUDITOR.

Robert A. McLean, F.C.A.

SECRETARY.

Edgar Worthington,
The Institution of Mechanical Engineers,
Storey's Gate, St. James's Park, London, S.W.
Telegraphic Address :—*Mech, London.* Telephone :—*Westminster*, 264.

THE INSTITUTION OF MECHANICAL ENGINEERS.

Memorandum of Association.

AUGUST 1878.

1st. The name of the Association is "THE INSTITUTION OF MECHANICAL ENGINEERS."

2nd. The Registered Office of the Association will be situate in England.

3rd. The objects for which the Association is established are:—

(A.) To promote the science and practice of Mechanical Engineering and all branches of mechanical construction, and to give an impulse to inventions likely to be useful to the Members of the Institution and to the community at large.

(B.) To enable Mechanical Engineers to meet and to correspond, and to facilitate the interchange of ideas respecting improvements in the various branches of mechanical science, and the publication and communication of information on such subjects.

(C.) To acquire and dispose of property for the purposes aforesaid.

(D.) To do all other things incidental or conducive to the attainment of the above objects or any of them.

4th. The income and property of the Association, from whatever source derived, shall be applied solely towards the promotion of the objects of the Association as set forth in this Memorandum of Association, and no portion thereof shall be paid or transferred directly or indirectly, by way of dividend, bonus, or otherwise howsoever, by way of profit to the persons who at any time are or have been Members of the Association, or to any of them, or to any person claiming through any of them: Provided that nothing herein contained shall prevent the payment in good faith of remuneration to any officers or servants of the Association, or to any Member of the Association, or other person, in return for any services rendered to the Association, or prevent the giving of privileges to the Members of the Association in attending the meetings of the Association, or prevent the borrowing of money (under such powers as the Association and the Council thereof may possess) from any Member of the Association, at a rate of interest not greater than five per cent. per annum.

5th. The fourth paragraph of this Memorandum is a condition on which a licence is granted by the Board of Trade to the Association in pursuance of Section 23 of the Companies Act 1867. For the purpose of preventing any evasion of the terms of the said fourth paragraph, the Board of Trade may from time to time, on the application of any Member of the Association, impose further conditions, which shall be duly observed by the Association.

6th. If the Association act in contravention of the fourth paragraph of this Memorandum, or of any such further conditions, the liability of every Member of the Council shall be unlimited; and the liability of every Member of the Association who has received any such dividend, bonus, or other profit as aforesaid, shall likewise be unlimited.

7th. Every Member of the Association undertakes to contribute to the Assets of the Association, in the event of the same being wound up during the time that he is a Member, or within one year afterwards, for payment of the debts and liabilities of the Association contracted before the time at which he ceases to be a Member, and of the costs, charges, and expenses for winding up the same, and for the adjustment of the rights of the contributories amongst themselves, such amount as may be required not exceeding Five Shillings, or in case of his liability becoming unlimited such other amount as may be required in pursuance of the last preceding paragraph of this Memorandum.

8th. If upon the winding up or dissolution of the Association there remains, after the satisfaction of all its debts and liabilities, any property whatsoever, the same shall not be paid to or distributed among the Members of the Association, but shall be given or transferred to some other Institution or Institutions having objects similar to the objects of the Association, to be determined by the Members of the Association at or before the time of dissolution; or in default thereof, by such Judge of the High Court of Justice as may have or acquire jurisdiction in the matter.

Articles of Association.

February 1893.

(*Article* 23 *revised March* 1902.)

INTRODUCTION.

Whereas an Association called "The Institution of Mechanical Engineers" existed from 1847 to 1878 for objects similar to the objects expressed in the Memorandum of Association of the Association (hereinafter called "the Institution") to which these Articles apply;

And whereas the Institution was formed in 1878 for furthering and extending the objects of the former Institution, by a registered Association, under the Companies Acts 1862 and 1867;

And whereas terms used in these Articles are intended to have the same respective meanings as they have when used in those Acts, and words implying the singular number are intended to include the plural number, and *vice versâ*;

Now therefore it is hereby agreed as follows:—

CONSTITUTION.

1. For the purpose of registration the number of members of the Institution is unlimited.

MEMBERS, ASSOCIATE MEMBERS, GRADUATES, ASSOCIATES, AND HONORARY LIFE MEMBERS.

2. The present Members of the Institution, and such other persons as shall be admitted in accordance with these Articles, and none others, shall be Members of the Institution, and be entered on the register as such.

3. Any person may become a Member of the Institution who shall be qualified and elected as hereinafter mentioned, and shall agree to become such Member, and shall pay the entrance fee and first subscription accordingly.

4. The qualification of Members shall be prescribed by the By-laws from time to time in force, as provided by the Articles.

5. The election of Members shall be conducted as prescribed by the By-laws from time to time in force, as provided by the Articles.

6. In addition to the persons already admitted as Graduates, Associates, and Honorary Life Members respectively, the Institution may admit such persons as may be qualified and elected in that behalf as Associate Members, Graduates, Associates, and Honorary Life Members respectively of the Institution, and may confer upon them such privileges as shall be prescribed by the By-laws from time to time in force, as provided by the Articles: provided that no Associate Member, Graduate, Associate, or Honorary Life Member shall be deemed to be a Member within the meaning of the Articles.

7. The qualification and mode of election of Associate Members, Graduates, Associates, and Honorary Life Members shall be prescribed by the By-laws from time to time in force, as provided by the Articles.

8. The rights and privileges of every Member, Associate Member, Graduate, Associate, or Honorary Life Member shall be personal to himself, and shall not be transferable or transmissible by his own act or by operation of law.

ENTRANCE FEES AND SUBSCRIPTIONS.

9. The Entrance Fees and Subscriptions of Members, Associate Members, Graduates, and Associates shall be prescribed by the By-laws from time to time in force, as provided by the Articles.

EXPULSION.

10. If any Member, Associate Member, Graduate, or Associate shall leave his subscription in arrear for two years, and shall fail to pay such arrears within three months after a written application has been sent to him by the Secretary, his name may be struck off the register by the Council at any time afterwards, and he shall thereupon cease to have any rights as a Member, Associate Member, Graduate, or Associate, but he shall nevertheless continue liable to pay the arrears of subscription due at the time of his name being so struck off: provided always that this regulation shall not be construed to compel the Council to remove any name, if they shall be satisfied the same ought to be retained.

11. The Council may refuse to continue to receive the subscriptions of any person who shall have wilfully acted in contravention of the regulations of the Institution, or who shall in the opinion of the Council have been guilty of such conduct as shall have rendered him unfit to continue to belong to the Institution; and may remove his name from the register, and he shall thereupon cease to be a Member, Associate Member, Graduate, or Associate (as the case may be) of the Institution.

GENERAL MEETINGS.

12. The General Meetings shall consist of the Ordinary Meetings, the Annual General Meeting, and of Special Meetings as hereinafter defined.

13. The Annual General Meeting shall take place in London in one of the first four months of every year. The Ordinary Meetings shall take place at such times and places as the Council shall determine.

14. A Special Meeting may be convened at any time by the Council, and shall be convened by them whenever a requisition signed by twenty Members or Associate Members of the Institution,

specifying the object of the Meeting, is left with the Secretary. If for fourteen days after the delivery of such requisition a Meeting be not convened in accordance therewith, the Requisitionists or any twenty Members or Associate Members of the Institution may convene a Special Meeting in accordance with the requisition. All Special Meetings shall be held in London.

15. Seven clear days' notice of every Meeting, specifying generally the nature of any special business to be transacted at any Meeting, shall be given to every person on the register of the Institution, except as provided by Article 35, and no other special business shall be transacted at such Meeting; but the non-receipt of such notice shall not invalidate the proceedings of such Meeting. No notice of the business to be transacted (other than such ballot lists as may be requisite in case of elections) shall be required in the absence of special business.

16. Special business shall include all business for transaction at a Special Meeting, and all business for transaction at every other Meeting, with the exception of the reading and confirmation of the Minutes of the previous Meeting, the election of Members, Associate Members, Graduates, and Associates, and the reading and discussion of communications as prescribed by the By-laws, or by any regulations of the Council made in accordance with the By-laws.

PROCEEDINGS AT GENERAL MEETINGS.

17. Twenty Members or Associate Members shall constitute a quorum for the purpose of a Meeting other than a Special Meeting. Thirty Members or Associate Members shall constitute a quorum for the purpose of a Special Meeting.

18. If within thirty minutes after the time fixed for holding the Meeting a quorum is not present, the Meeting shall be dissolved, and all matters which might, if a quorum had been present, have been done at a Meeting (other than a Special Meeting) so dissolved, may forthwith be done on behalf of the Meeting by the Council.

19. The President shall be Chairman at every Meeting, and in *his absence one of the Vice-Presidents; and in the absence of all* Vice-Presidents a Member of Council shall take the chair; and if no Member of Council be present and willing to take the chair, the Meeting shall elect a Chairman.

20. The decision of a General Meeting shall be ascertained by show of hands, unless, after the show of hands, a poll is forthwith demanded; and by a poll, when a poll is thus demanded. The manner of taking a show of hands or a poll shall be in the discretion of the Chairman; and an entry in the Minutes, signed by the Chairman, shall be sufficient evidence of the decision of the General Meeting. Each Member and Associate Member shall have one vote and no more. In case of equality of votes the Chairman shall have a second or casting vote: provided that this Article shall not interfere with the provisions of the By-laws as to election by ballot.

21. The acceptance or rejection of votes by the Chairman shall be conclusive for the purpose of the decision of the matter in respect of which the votes are tendered: provided that the Chairman may review his decision at the same Meeting, if any error be then pointed out to him.

BY-LAWS.

22. The By-laws set forth in the schedule to these Articles, and such altered and additional By-laws as shall be substituted or added as hereinafter mentioned, shall regulate all matters by the Articles left to be prescribed by the By-laws, and all matters which consistently with the Articles shall be made the subject of By-laws. Alterations in, and additions to, the By-laws, may be made only by resolution of the Members and Associate Members at an Annual General Meeting, after notice of the proposed alteration or addition has been announced at the previous Ordinary Meeting, and not otherwise.

COUNCIL.

23. The Council of the Institution shall be chosen from the Members only, and shall consist of one President, six Vice-Presidents, twenty-one ordinary Members of Council, and of the Past-Presidents. The President, two Vice-Presidents, and seven Members of Council (other than Past-Presidents), shall retire at each Annual General Meeting, but shall be eligible for re-election. The Vice-Presidents and Members of Council to retire each year shall, unless the Council agree otherwise among themselves, be chosen from those who have been longest in office, and in cases of equal seniority shall be determined by ballot.

24. The election of a President, Vice-Presidents, and Members of Council, to supply the place of those retiring at the Annual General Meeting, shall be conducted in such manner as shall be prescribed by the By-laws from time to time in force, as provided by the Articles.

25. The Council may supply any casual vacancy in the Council (including any casual vacancy in the office of President) which shall occur between one Annual General Meeting and another; and the President, Vice-Presidents, or Members of Council so appointed by the Council shall retire at the succeeding Annual General Meeting. Vacancies not filled up at any such Meeting shall be deemed to be casual vacancies within the meaning of this Article.

OFFICERS.

26. The Treasurer, Secretary, and other employés of the Institution shall be appointed and removed in the manner prescribed by the By-laws from time to time in force, as provided by the Articles. Subject to the express provisions of the By-laws, the officers and servants of the Institution shall be appointed and removed by the Council.

27. The powers and duties of the officers of the Institution shall, subject to any express provision in the By-laws, be determined by the Council.

POWERS AND PROCEDURE OF COUNCIL.

28. The Council may regulate their own procedure, and delegate any of their powers and discretions to any one or more of their body, and may determine their own quorum: if no other number is prescribed, three members of Council shall form a quorum.

29. The Council shall manage the property, proceedings, and affairs of the Institution, in accordance with the By-laws from time to time in force.

30. The Treasurer may, with the consent of the Council, invest in the name of the Institution any moneys not immediately required for the purposes of the Institution in or upon any of the following investments (that is to say):—

(A) The Public Funds, or Government Stocks of the United Kingdom, or of any Foreign or Colonial Government guaranteed by the Government of the United Kingdom.

(B) Real or Leasehold Securities, or in the purchase of real or leasehold properties in Great Britain or Ireland.

(C) Debentures, Debenture Stock, or Guaranteed or Preference Stock, of any Company incorporated by special Act of Parliament, the ordinary Shareholders whereof shall at the time of such investment be in actual receipt of half-yearly or yearly dividends.

(D) Stocks, Shares, Debentures, or Debenture Stock of any Railway, Canal, or other Company, the undertaking whereof is leased to any Railway Company at a fixed or fixed minimum rent.

(E) Stocks, Shares, or Debentures of any East Indian Railway or other Company, which shall receive a contribution from His Majesty's East Indian Government of a fixed annual percentage on their capital, or be guaranteed a fixed annual dividend by the same Government.

(F) The security of rates levied by any corporate body empowered to borrow money on the security of rates, where such borrowing has been duly authorised by Act of Parliament.

31. The Council may, with the authority of a resolution of the Members and Associate Members in General Meeting, borrow moneys for the purposes of the Institution on the security of the property of the Institution, or otherwise at their discretion.

32. No act done by the Council, whether *ultra vires* or not, which shall receive the express or implied sanction of the Members and Associate Members in General Meeting, shall be afterwards impeached by any member of the Institution on any ground whatsoever, but shall be deemed to be an act of the Institution.

NOTICES.

33. A notice may be served by the Council upon any Member, Associate Member, Graduate, Associate, or Honorary Life Member, either personally or by sending it through the post in a prepaid letter addressed to him at his registered place of abode.

34. Any notice, if served by post, shall be deemed to have been served at the time when the letter containing the same would be delivered in the ordinary course of the post; and in proving such service it shall be sufficient to prove that the letter containing the notice was properly addressed and put into the post office.

35. No Member, Associate Member, Graduate, Associate, or Honorary Life Member, not having a registered address within the United Kingdom, shall be entitled to any notice; and all proceedings may be had and taken without notice to such member, in the same manner as if he had had due notice.

By-laws.

(*Last Revision, February* 1907.)

MEMBERS.

1. No Candidate shall be elected a Member, or be transferred into the class of Members, unless he is at least 30 years of age, and has produced evidence, to the satisfaction of the Council, either

I. That he—
- (a) Has received a good general and scientific education;
- (b) Has been regularly trained as a Mechanical Engineer; and
- (c) Has been engaged for a sufficient period in an important position of independent responsibility in the direction of engineering work:

Or II. That he—
- (d) Has received a thorough scientific education;
- (e) Has had sufficient practical experience as a Mechanical Engineer; and
- (f) Has for a sufficient period held an important position of independent responsibility in connection with engineering work:

Or III. That he—
- (g) Has attained to a position of such eminence in the profession, or in the direction of engineering work, as to qualify him, in the opinion of the Council, for the distinction of Membership.

ASSOCIATE MEMBERS.

2. No Candidate shall be elected an Associate Member, unless he is at least 25 years of age, and has produced evidence, to the satisfaction of the Council, either

I. That he—
  (a) Has received a good general education;
  (b) Has been regularly trained as a Mechanical Engineer; and
  (c) Has had subsequent employment for at least one year in a responsible position in the direction or design of engineering work, and is actually so engaged at the time of his application for Election:

Or II. That he—
  (d) Has received a good general and scientific education;
  (e) Has had sufficient practical experience as a Mechanical Engineer; and
  (f) Has had subsequent employment for at least one year in a responsible position in the direction or design of engineering work, and is actually so engaged at the time of his application for Election.

GRADUATES.

3. Graduates shall be persons not under 18 years of age, who shall satisfy the Council that they have received a good general education, and have received, or are receiving, regular training as Mechanical Engineers, and that they have received, or intend to obtain, sufficient practical and scientific training to fit them for employment in responsible positions as Mechanical Engineers. No person shall be elected a Graduate after the age of 25 years.

Graduates may not continue as such if they cease to follow the profession of Engineering, nor in any case beyond the age of 28 years.

ASSOCIATES.

4. Associates shall be persons of at least 30 years of age, who not being Mechanical Engineers by profession, yet by reason of their attainments in science, or in any of the arts allied to, or having interests in common with, Engineering, may be deemed by the Council to be worthy of the distinction of Associateship.

TRANSFERENCE.

5. At the discretion of the Council properly qualified Associate Members may on application be transferred to the class of Members, and properly qualified Associates may be transferred to the classes of Associate Members or Members.

HONORARY LIFE MEMBERS.

6. The Council shall have the power to nominate as Honorary Life Members persons of eminent scientific attainments.

PRIVILEGES OF MEMBERSHIP.

7. The Members, Associate Members, Graduates, Associates, and Honorary Life Members shall have notice of, and the privilege to attend, all Meetings; but Members and Associate Members only shall be entitled to vote thereat.

8. The abbreviated distinctive Titles for indicating the connection with the Institution, of Members, Associate Members, Graduates, Associates, or Honorary Life Members thereof, shall be the following:—for Members, M. I. Mech. E.; for Associate Members, A. M. I. Mech. E.; for Graduates, G. I. Mech. E.; for Associates, A. I. Mech. E.; for Honorary Life Members, Hon. M. I. Mech. E.

9. Subject to such regulations as the Council may from time to time prescribe, any Member, Associate Member, or Associate may upon application to the Secretary obtain a Certificate of his membership or other connection with the Institution. Every such certificate shall remain the property of, and shall on demand be returned to, the Institution.

ENTRANCE FEES AND SUBSCRIPTIONS.

10. Each Member shall pay an Annual Subscription of £3, and on election an Entrance Fee of £2.

11. Each Associate Member shall pay an Annual Subscription of £2 10*s*., and on election an Entrance Fee of £1. If afterwards transferred by the Council to the class of Members, he shall pay on transference 10*s*. additional Subscription for the current year, and £1 additional Entrance Fee.

12. Each Graduate shall pay an Annual Subscription of £1 10*s*., but no Entrance Fee.

13. Each Associate shall pay an Annual Subscription of £2 10*s*., and on election an Entrance Fee of £1. If afterwards transferred by the Council to the class of Associate Members, he shall pay on transference no additional Subscription or Entrance Fee. If transferred direct to the class of Members, he shall pay on transference 10*s*. additional Subscription for the current year, and £1 additional Entrance Fee.

14. All Subscriptions shall be payable in advance, and shall become due on the 1st day of January in each year; and the first Subscription of each Member, Associate Member, Graduate, and Associate, shall date from the 1st day of January in the year of his election, and shall, except in the cases provided for by By-law 15, entitle him to the Proceedings published during that year.

15. In the case of each Member, Associate Member, Graduate, or Associate, elected in the last three months of any year, the first Subscription shall cover both the year of Election and the succeeding year, but shall only entitle the person elected to the Proceedings published after his Election.

16. Any Member, Associate Member, or Associate, whose Subscription is not in arrear, may at any time compound for his Subscription for the current and all future years by the payment of Fifty Pounds, if paid in any one of the first five years of his membership. If paid subsequently, the sum of Fifty Pounds shall be reduced by One Pound per annum for every year of membership after five years. All compositions shall be deemed to be capital moneys of the Institution.

17. No Proceedings or Ballot Lists or Certificates shall be sent to Members, Associate Members, Graduates, or Associates, who are in arrear with their Subscriptions more than twelve months, and whose Subscriptions have not been remitted by the Council as hereinafter provided. (By-law 18.)

18. The Council may at their discretion reduce or remit the Annual Subscription, or the arrears of Annual Subscription, of any Member or Associate Member who shall have been a subscribing member of the Institution for twenty years, and shall have become unable to continue the Annual Subscription provided by these By-laws.

ELECTION OF MEMBERS, ASSOCIATE MEMBERS, GRADUATES, AND ASSOCIATES.

19. Every recommendation for Election shall be in accordance with Form A or Form B in the Appendix, and shall be forwarded to the Secretary who shall lay it before the Council. The Form A must be signed by the Candidate and by not less than five Members or Associate Members, and the Form B by the Candidate and by not less than three Members or Associate Members.

20. All Elections shall take place by Ballot of the Members and Associate Members, four-fifths of the votes given being necessary for Election.

21. Every recommendation for Election shall be considered by the Council. The Ballot Lists shall contain only such names in each class as are approved by the Council for Election. Each List of approved Candidates shall be signed by the Chairman of the Council Meeting authorising its issue. The Ballot Lists shall be classified, and shall specify the name, occupation and address of each Candidate, and the names of his Proposer and Seconder; they shall be sent to Members and Associate Members only, and shall be opened by, or in the presence of, a Committee appointed for that purpose by the Council. The Committee shall report the result of the Ballot to the Council.

22. The result of each Ballot shall be declared at the next General Meeting.

23. When a Candidate is elected, the Secretary shall give him notice thereof according to Forms D or E in the Appendix; but his name shall not be added to the register of the Institution until he shall have paid his Entrance Fee and first Annual Subscription.

24. In case of non-Election, no mention thereof shall be made in the Minutes, nor any notice given to the unsuccessful Candidate.

25. An Associate Member desirous of being transferred to the class of Members, or an Associate to the class of Associate Members, or to that of Members, shall forward to the Secretary a recommendation, according to Form C in the Appendix, signed by not less than five Members or Associate Members, which shall be laid before the Council. On their approval being given, the Secretary shall notify the same to the Candidate according to Form F; but his name shall not be added to the list of Members or Associate Members until he shall have paid the additional Entrance Fee (if any), and the additional Subscription (if any) for the current year.

ELECTION OF PRESIDENT, VICE-PRESIDENTS, AND MEMBERS OF COUNCIL.

26. At the General Meeting preceding the Annual General Meeting, the Council are to present a list of Members nominated by them. Any Member or Associate Member shall then be entitled to add to the list of Candidates. A Ballot List of the proposed names shall be forwarded to each Member and Associate Member. The Ballot Lists shall be opened only on the day of the Annual General Meeting, in the presence of the Council, by a Committee appointed for that purpose.

APPOINTMENT AND DUTIES OF OFFICERS.

27. The Treasurer shall be a Banker, and shall hold the uninvested funds of the Institution, except the moneys in the hands of the Secretary for current expenses. He shall be appointed, on the recommendation of the Council, by the Members and Associate Members at a General or Special Meeting, and shall hold office at the pleasure of the Council.

28. The Secretary of the Institution shall be appointed, on the recommendation of the Council, as and when a vacancy occurs, by the Members and Associate Members at a General or Special Meeting, and shall be removable by the Council upon six months' notice from any day. The Secretary shall give the same notice. The Secretary shall devote the whole of his time to the work of the Institution, and shall not engage in any other business or profession.

29. It shall be the duty of the Secretary, under the direction of the Council, to conduct the correspondence of the Institution; to attend all meetings of the Institution, and of the Council, and of Committees; to take minutes of the proceedings of such meetings; to read the minutes of the preceding meetings, and all communications

that he may be ordered to read; to superintend the publication of such Papers as the Council may direct; to have the charge of the Institution building and library; to direct the collection of the Subscriptions, and the preparation of the account of expenditure of the funds; and to present all accounts to the Council for inspection and approval. He shall also engage (subject to the approval of the Council), and be responsible for, all persons employed under him, and set them their portions of work and duties. He shall conduct the ordinary business of the Institution, in accordance with the Articles and By-laws and the directions of the President and Council; and shall refer to the President in any matters of difficulty or importance, requiring immediate decision.

30. The Auditor shall be a Fellow of the Institute of Chartered Accountants, and shall be appointed annually by the Members and Associate Members at a General or a Special Meeting, at a remuneration to be then fixed by the Members and Associate Members. The yearly Accounts, after being duly audited, shall be presented by the Council to the Annual General Meeting.

MEETINGS.

31. Every Paper shall be submitted to the Council for approval, and after approval shall be read at a General Meeting, or shall be printed in the Proceedings without having been read at a General Meeting, as may be directed by the Council.

32. The proceedings at the General Meetings shall, as far as practicable, conform to the following order:—

1st. The Chair shall be taken at such hour as the Council may direct.

2nd. The Minutes of the previous Meeting shall be read by the Secretary, and, after being approved as correct, shall be signed by the Chairman.

3rd. The result of the examination of the Ballot Lists shall be declared to the Meeting, and the names of the Members, Associate Members, Graduates, and Associates elected shall be announced. Any Transferences made by the Council since the last Meeting shall also be announced.

4th. Papers approved by the Council shall be read by the Secretary, or by the Author, as may be directed by the Council.

33. Each Member or Associate Member shall have the privilege of introducing one friend to any of the General Meetings; but, during such portion of any Meeting as may be devoted to any business connected with the management of the Institution, visitors shall be requested by the Chairman to withdraw, if any Member or Associate Member asks that this shall be done.

34. Every Member, Associate Member, Graduate, Associate, or Visitor, shall write his name and residence in a book to be kept for the purpose, on entering each Meeting.

35. The discussion upon any Paper may be adjourned at the discretion of the Chairman.

36. Seven clear days' notice at least shall be given of every meeting of the Council. Such notice shall specify generally the business to be transacted by the meeting. No business involving the expenditure of the funds of the Institution (except by way of payment of current salaries and accounts) shall be transacted at any Council meeting unless specified in the notice convening the meeting.

MISCELLANEOUS.

37. The President shall *ex officio* be a member of all Committees of the Council.

38. All Communications to the Institution, unless declined, shall be the property of the Institution, and shall be published only by the authority of the Council.

39. None of the property of the Institution shall be taken out of the premises of the Institution without the consent of the Council.

40. All Donations to the Institution shall be enumerated in the Annual Report of the Council presented to the Annual General Meeting.

41. Advance copies of Papers to be read at the Meetings may be sent to members on application to the Secretary.

42. All Books, Drawings, Communications, etc., shall be accessible to the members of the Institution at all reasonable times.

43. Graduates and Associates elected prior to 1893 shall, notwithstanding anything in these By-laws contained, retain the privileges set out in the By-laws as revised in January 1890.

APPENDIX.

FORM A.

(PROPOSAL AS MEMBER, ASSOCIATE MEMBER, OR ASSOCIATE.)

Name in full ....
Designation or Occupation ....
Business Address ....
being.................. years of age, and desirous of admission into The Institution of Mechanical Engineers, we, the undersigned proposer and seconder from our *personal knowledge*, and (at least) three other supporters, propose and recommend him as a proper person to belong to the Institution.

Witness our hands, this .... day of ....

Five Members' or Associate Members' Signatures are required.

Proposed from *personal knowledge* by ....
Seconded from *personal knowledge* by ....
Supported from *personal knowledge* by ....
Supported from *trustworthy information* by ....

Those who sign this Form are desired to append their initials to the portions of the statement of which they have personal knowledge.

ENGAGEMENT.

I, the undersigned, do hereby agree that, in the event of my election as Member, Associate Member, or Associate, I will be governed by the regulations of The Institution of Mechanical Engineers as they are now formed or as they may hereafter be altered; that I will advance the objects of the Institution as far as shall be in my power, and will attend the Meetings thereof as often as I conveniently can: provided that, whenever I shall signify in writing to the Secretary that I am desirous of withdrawing from the Institution, I shall (after the payment of any arrears which may be due by me at that period) be free from this obligation.

Signature of Candidate..

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	* Initials of Supporters.
Date and Place of Birth..	....
General Education (with dates)..	....
Technical Education (with dates, subjects taken, and successes gained)..	....
Apprenticeship (with dates, and particulars of training received)	....
Subsequent Career (with dates, and positions held)...............	....
Brief Details of most important Mechanical Engineering work for which Candidate has been personally responsible.........	....
Membership in other Societies..	....

Signature of Candidate..

* Members supporting this proposal are requested to place their initials against those particulars of the Candidate's career of which they have personal knowledge.

FORM B.

(Proposal as Graduate.)

Name in full..

Designation or Occupation...

Business Address..

Address for communications..

being......................years of age, and desirous of becoming a Graduate of The Institution of Mechanical Engineers, we, the undersigned proposer and seconder from our *personal knowledge*, and the other signer or signers from trustworthy information, propose and recommend him as a proper person to become a Graduate thereof.

Witness our hands, this...........day of.......................................

Three Members' or Associate Members' Signatures are required.

Proposed from *personal knowledge* by..

Seconded from *personal knowledge* by..

Supported by...

Date and Place of Birth..

General Education (with dates)...

Technical Education (with dates, subjects taken, and successes gained).

Apprenticeship (with dates, and particulars of training received).

....

Subsequent Career (with dates, and positions held)...............

....

Signature of Candidate.........................

I, the undersigned, do hereby agree that in the event of my election I will be governed during my Graduateship by the regulations of The Institution of Mechanical Engineers, as they are now formed or as they may hereafter be altered: provided that, whenever I shall signify in writing to the Secretary that I am desirous of withdrawing from the Institution, I shall (after the payment of any arrears which may be due by me at that period) be free from this obligation.

Signature of Candidate..

FORM C.

(PROPOSAL FOR TRANSFERENCE.)

Name in full ....

Designation or Occupation..

Business Address ....

being...............years of age, and desirous of being transferred into the class of............................of The Institution of Mechanical Engineers, we, the undersigned, from our *personal knowledge*, recommend him as a proper person to be so transferred by the Council.

Witness our hands, this............day of..

Five Members' or Associate Members' Signatures are required, from personal knowledge.

(Members of the Council do not sign this form.)

Proposed by...

Seconded by ....

Those who sign this Form are desired to append their initials to the portions of the statement of which they have personal knowledge.

	* Initials of Supporters.
Qualifications (*since joining the Institution*)........................	....
....	....
Signature of Candidate..	

* Members supporting this proposal are requested to place their initials against those particulars of the Candidate's career of which they have personal knowledge.

FORM D.

Sir,—I have the pleasure to inform you that on the.......................... you were elected a.................of The Institution of Mechanical Engineers. For the ratification of your election in conformity with the rules, it is requisite that your Entrance Fee and first Annual Subscription be paid, the amounts of which are...............and..................respectively. If these be not received within two months from the present date, the Election will become void.

I am, Sir, Your obedient servant,

Secretary.

FORM E.

Sir,—I have the pleasure to inform you that on the..........................
you were elected a **Graduate** of The Institution of Mechanical Engineers. For the ratification of your election in conformity with the rules, it is requisite that your first Annual Subscription be paid, the amount of which *is £1 10s. 0d. If this* be not received within two months from the present *date, the Election* will become void.

I am, Sir, Your obedient servant,
Secretary.

FORM F.

Sir,—I have the pleasure to inform you that the Council have approved of your being transferred to the class of........................of The Institution of Mechanical Engineers. For the ratification of your Transference in conformity with the rules, it is requisite that your additional Entrance Fee and additional Annual Subscription for the current year be paid, the amounts of which are..................and..................respectively. If these be not received within two months from the present date, the Transference will become void.

I am, Sir, Your obedient servant,
Secretary.

The Institution of Mechanical Engineers.

PROCEEDINGS.

JANUARY 1911.

An ORDINARY GENERAL MEETING was held at the Institution on Friday, 20th January 1911, at Eight o'clock p.m.; JOHN A. F. ASPINALL, Esq., President, in the chair.

The Minutes of the previous Meeting were read and confirmed.

The PRESIDENT announced that the Council, under Article 25, had appointed Mr. MICHAEL LONGRIDGE a Vice-President, to fill the vacancy caused by the nomination of Mr. Edward B. Ellington as President. His name was therefore included in the Retiring List.

In accordance with Article 23, the President, two Vice-Presidents, and seven Members of Council would retire at the ensuing Annual General Meeting; and the list of those retiring was as follows:—

PRESIDENT.

JOHN A. F. ASPINALL, ... Manchester.

VICE-PRESIDENTS.

H. F. DONALDSON, C.B.,* . . . . . . Woolwich.
MICHAEL LONGRIDGE,* . . . . . . Manchester.

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* Appointed during the year.

Members of Council.

Sir Robert A. Hadfield, F.R.S.,	Sheffield.
Edward Hopkinson, D.Sc.,	Manchester.
Henry A. Ivatt,	Doncaster.
William H. Patchell,*	London.
The Right Hon. Lord Pirrir, K.P., P.C., LL.D.,	Belfast.
Captain H. Riall Sankey, R.E., ret.,*	London.
Sir John I. Thornycroft, LL.D., F.R.S.,	London.

The following Officers were nominated by the Council for election :—

For President.

Edward B. Ellington,	London.

For Vice-Presidents.

H. F. Donaldson, C.B.,	Woolwich.
Michael Longridge,	Manchester.

For Members of Council.

Sir Robert A. Hadfield, F.R.S.,	Sheffield.
Edward Hopkinson, D.Sc.,	Manchester.
Henry A. Ivatt,	Doncaster.
William H. Patchell,	London.
Captain H. Riall Sankey, R.E., ret.,	London.

The following Nominations were also made by the Council for the election at the Annual General Meeting :—

For Members of Council.

Election as Member.		
1908.	Dugald Clerk, F.R.S.,	London.
1870.	Charles Hawksley,	London.
1899.	George Hughes,	Horwich.
1910.	Engineer Vice-Admiral Sir H. J. Oram, K.C.B.,	London.
1882.	A. Basil Wilson,	Belfast.

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* Appointed during the year.

All of the foregoing had consented to the Nomination.

After an interval, no other names being added, the President announced that the foregoing names would accordingly constitute the nomination list for the Election of Officers at the Annual General Meeting.

The President announced that the Ballot Lists for the election of New Members had been opened by a Committee appointed by the Council, and that the following twenty-eight candidates were found to be duly elected:—

MEMBERS.

Clarke, Joseph,	Ocean Island, C.P.
Howard, John,	Calcutta.
Lyon, Alexander Gordon,	London.
Morgan, Lewis Henry,	Nantwich.
Nice, Pearce Savell,	Valparaiso.
Park, George Molyneux,	Blackburn.
Williams, Bernard Edward,	Birmingham.

ASSOCIATE MEMBERS.

Airey, William Wilkinson,	Blackburn.
Allison, Bertram John,	Fishguard.
Bakewell, Frederic John,	Buenos Aires.
Burnside, Francis Ingoldsby Massy,	Coventry.
Calverley, Vincent,	Shipley.
Clench, Edward Claude Shakespeare,	Wembley.
Craven, Arthur Douglas,	Leeds.
Dowell, Herbert,	Bessbrook, Co. Armagh.
Kavanagh, Charles Joseph,	Calcutta.
McLaren, Hugh,	Accra, Gold Coast.
Owen, Llewelyn Edward,	Birmingham.
Pudsey, Fawcett,	Hull.
Smorthwaite, George William,	London.

Stone, Thomas Alfred Foote	Roorkee, India.
Thorne, Henry Thomas	London.

GRADUATES.

Bramwell, Francis Herbert	Teddington.
Briggs, Roland Hunter	London.
Dawson, Herbert Percy	Newport, Mon.
Forsyth, William James	London.
Hill, Arthur Trenchard	London.
Meyjes, Anthony Charles Dorian	Grantham.

The President announced that the following Transference had been made by the Council:—

Associate Member to Member.

Shaw, Arthur Henry	Ilford.

The following Paper was read and partly discussed:—

"Modern Electrical Dock-Equipment, with special reference to Electrically-operated Coal-Hoists"; by Mr. Walter Dixon and Mr. George H. Baxter, *Members*, of Glasgow.

The Meeting terminated shortly before Ten o'clock. The attendance was 146 Members and 78 Visitors.

MODERN ELECTRICAL DOCK-EQUIPMENT, WITH SPECIAL REFERENCE TO ELECTRICALLY-OPERATED COAL-HOISTS.

BY MR. WALTER DIXON AND MR. GEORGE H. BAXTER, *Members*,
OF GLASGOW.

At the Summer Meeting of the Institution of Mechanical Engineers, held at Cardiff in July 1906, three Papers dealing with Coal Shipping and Dock Appliances were read. The general impression in these Papers, and particularly in the discussion thereon, appeared to be that hydraulic power was the only power sufficiently reliable for such appliances, and that Electricity, no matter what other fields it may enter, was certainly not suitable for dock equipments, particularly coaling-cranes and tips.

A review of the history of what had already been done with electric power in docks may have justified such an impression, although as far back as 1903, Mr. Walter Pitt, in a Paper before the Institution of Civil Engineers, showed that electric jib-cranes compared very favourably on all points with those operated by hydraulics, quoting some figures obtained by Mr. Baxter, as a result of a comparison between a hydraulic crane and an electric crane at

Princes Dock, Glasgow. British Dock Engineers have confined themselves very largely to electric jib-cranes and capstans, which until recently were chiefly modifications of the hydraulic type, very *little original design being employed, the electrical plant being simply applied to machines already designed.*

The authors fully appreciate all the merits of hydraulics, and that this form of power, having been thoroughly developed, is very safe and reliable, and, excepting where frost, moving ground or other natural objections arise, is, perhaps, under favourable conditions, not inferior to electric power. Where, however, in addition to reliability, economical working together with cleanliness and great flexibility is desirable, the inherent advantages of electricity at once become apparent, although it may not be possible to claim that one system is better than another for any particular case, as every equipment must depend on local and other considerations. Prior to recent electrical developments, there were undoubtedly cases in which hydraulics had a distinct preference over electricity, and, as an instance of this, reference may be made (as was done in the discussion on the Papers referred to above) to the difficulty of applying electricity to the shipment of coal either by cranes or by tips. This particular difficulty, however, has now been overcome, and notwithstanding the vast hydraulic equipments, electricity will occupy at least equally as important a place as hydraulic power in all future developments of docks. No doubt, in its early stages, the progress of electricity was considerably retarded by the absence of an *entente cordiale* between mechanical and electrical engineers. Since the electrical and mechanical parts have received combined consideration, the past few years' experience has proved that electrical plant is quite as reliable as hydraulic plant.

Rothesay Dock, situated on the Clyde, and belonging to the Clyde Navigation Trustees, the general construction of which has already been described by Mr. W. M. Alston, Civil Engineer to the Trustees,* is designed essentially for dealing with the shipment of coal, and the import of iron ore, limestone, and other minerals.

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* *Engineering*, 26 April 1907, p. 543.

Hydraulic or Electric Power.—When considering the equipment of this new dock, the question naturally arose as to whether the appliances should be worked by hydraulic or electric power, the appliances at the other docks of the Trustees at Glasgow being operated either by steam or hydraulic power, with the exception of one crane at Princes Dock, which had been erected for the purpose of comparing the relative advantages of the two systems. The results obtained from this crane were so favourable that no doubt was left as to the advantage of dealing with the ordinary class of machines, such as cranes, capstans, etc., electrically. The proposed installation of several large coal-hoists, however, rendered the problem one which had not hitherto been faced. The mechanical difficulties in connection with such hoists had already been solved, but the difficulty of dealing electrically with the large amount of horse-power required in a very short period, together with the necessity of providing for rapid acceleration and retardation, and absolute control under all conditions, will be readily appreciated by those acquainted with electric plant, and the question as to whether such hoists could be designed to embody all the good qualities of hydraulic hoists, and, at the same time avoid their disadvantages, both as regards the hoists themselves and the power-station, had yet to be answered.

It was at this stage recognized that the problem had developed into one which could not be adequately dealt with by the Mechanical Engineering Department without expert electrical advice, and Mr. Walter Dixon, joint author of this Paper, was appointed to collaborate with Mr. Baxter, Chief Mechanical Engineer to the Trustees, in the preparation of a scheme to embody the complete equipment of the dock. While two electrically-operated coal-hoists were at that time in existence on the Continent, these being duplicates of each other, and a great step forward in what could be accomplished electrically, they were obviously impossible for dealing with the problem as now presented.

It appeared to the authors, however, that, while the difficulties were great, they were not insurmountable, and, taking advantage of the latest electrical developments, they proceeded with the scheme, which has resulted in the construction of two hoists. These have now been in operation for over three years, during which time they have given no trouble, and have more than fulfilled the duties expected from them. In fact, so satisfactory have the results been that the two additional hoists now being erected will be, in all essentials, a repetition of the existing ones, differing only in some minor details. The dock equipment, while it may not be the largest installation in this country, embodies so many novel features and new developments that the authors consider it will be of interest to record what has so far been done.

The equipment is not yet completed, but sufficient time has elapsed since the commencement of working to speak with assurance as to what may be expected of it, and while complete records over three or four years, which are not yet available, would undoubtedly be an advantage, it is hoped that the following particulars will not be without their value and influence on future dock-development schemes. From Fig. 1 it will be seen that the appliances already erected consist of two 32-ton coal-hoists; eighteen 4-ton cranes; twenty-seven 1-ton capstans; two 18-foot tipping turntables; two 5-ton pier-head capstans; an underground distribution system, and an electric lighting installation, in addition to which two 32-ton coal-hoists and turntables, two 4½-ton transporters, three 4-ton cranes, and twelve capstans are in course of construction.

Supply of Electrical Power.—Having resolved upon electricity as the motive power, it was necessary to decide whether the requisite energy should be obtained from an outside source, or generated in a power-station erected for the purpose at the dock. It is generally recognized that, where a reliable public power supply is available, it is desirable to take advantage of such a supply, and so obviate a considerable capital expenditure. In many cases, however, an objection arises to this course as the supply available is usually on the three-phase alternating-current system, which, while it may be satisfactorily employed, is not so suitable for dock purposes as direct current; so that, if the best results are to be obtained, an

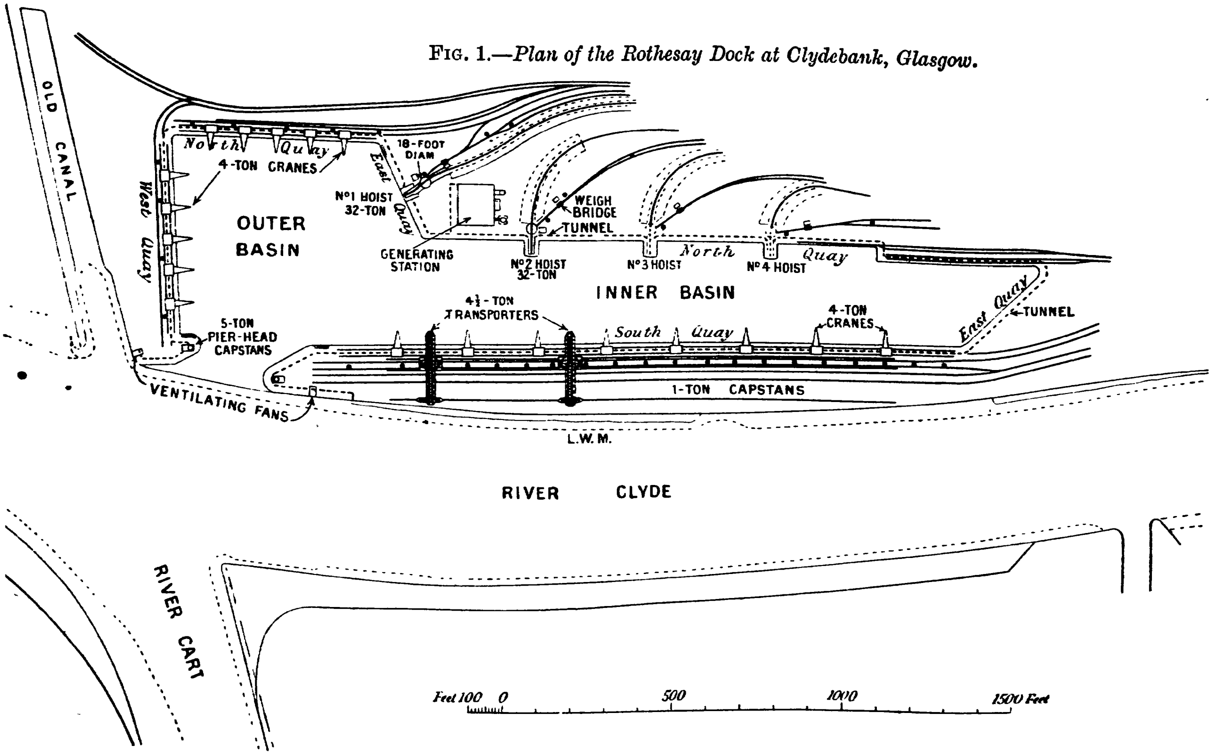


FIG. 1.—*Plan of the Rothesay Dock at Clydebank, Glasgow.*

appreciable portion of the capital which might otherwise have been saved in dispensing with steam-raising and generating plant might have to be utilized for providing converting and transforming plant.

Such a supply being available in close proximity to Rothesay Dock, the advisability of adopting it received due consideration, but the alternative of a separate generating-station was deemed to offer the best solution, it being found that power could be generated to better advantage and at a lower cost by plant specially designed for the purpose. The rates which are quoted at the present time by many of the public supply concerns are so reasonable that it is quite possible the requisite supply of energy may be economically obtained in this way, notwithstanding the first cost of and continual losses in the converting and transforming plant. The matter is one, however, which, in view of varying systems of charging for current, and the many subsidiary questions which arise, demands individual consideration in each case.

Generating Station.—The Generating Station, Fig. 2, Plate 1, a red-brick building, comprising boiler-house, engine-house, condenser-house and suitable store, also offices for the resident engineer and staff, is situated in a convenient central position on the North Quay of the Inner Basin.

The Steam-raising Plant, Fig. 3, consists of two water-tube boilers, each capable of evaporating 12,500 lb. of water per hour at a steam-pressure of 160 lb. per square inch, the steam being superheated about 150° F. by means of integral superheaters. The boilers are fitted with chain-grate mechanical stokers, which are driven by an electric motor. At present there are no mechanical appliances for dealing with the coal, but provision is made for their future adoption, and also for storage of coal. The feed-water is supplied by direct-acting pumps, and, after being partially heated by the exhaust steam from the feed-pumps in a feed-water heater, passes to an economizer of the high-pressure type, consisting of 190 tubes arranged in two groups, erected in the main flue in the boiler-house, suitable dampers being provided to divert the gases either through the economizer or direct to the chimney. The steam passes through two grease-extractors on its way to the condensing plant, which, together with the feed-pumping and heating plant, is erected in the condensing-house, Fig. 4, and comprises two complete sets of surface-condensing plant, each capable of dealing with 12,500 lb. of exhaust-steam per hour. The air-pumps are steam-driven by compound vertical engines, the circulating pumps being of the centrifugal type, driven direct by variable speed motors.

The foregoing brief summary of the steam raising and condensing plant and piping arrangement will serve to show that this is of the most efficient and modern type, and a more detailed description is perhaps beyond the scope of the present Paper, more especially as the generating plant with its auxiliaries, erected in the engine-house, being of an interesting nature, will be described at greater length.

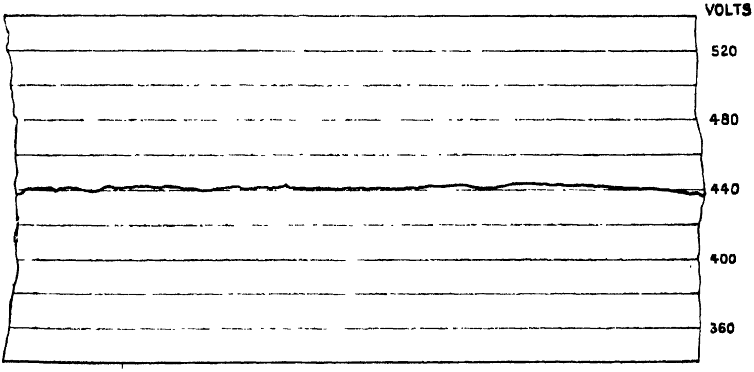
Generating Plant.—It is well known that the intermittent working of dock machinery causes excessive peak demands. If the generating plant is made of sufficient capacity to meet these demands it is large in proportion to the average load, and, as a result, in addition to being expensive in first cost, it does not run under the most economical conditions. In order, therefore, to keep the plant within reasonable dimensions, and at the same time to ensure economical running conditions, it has hitherto been the invariable practice to install a battery of accumulators with a reversible booster plant, in connection with dock installations. The possibility of adopting such a system, which has many good points, for Rothesay Dock was carefully considered, but, while it was recognized that it serves a very useful purpose under certain conditions of varying demands, such an installation would not adequately meet the more stringent requirements of the case, involving as it did the special demands of the coal-hoists. It was, therefore, decided to investigate the possibilities of further developing the system, where excessive loads have to be dealt with, of coupling a prime-mover, either electrically or steam-driven, to a generator in conjunction with a fly-wheel. It was apparent that if the special coal-hoist generators and a further generator for supplying power for ordinary dock purposes could be practically constructed in combination with a fly-wheel, it would be very economical, and would enable the usual battery of accumulators to be dispensed with, the fly-wheel taking care not only of the large peaks due to the coal-hoist but also of the smaller but more frequent demands of the other appliances.

The principal problem to be solved in this arrangement was to ensure a constant voltage at the terminals of the main generator supplying power for ordinary purposes, as, in addition to the varying loads which are usually dealt with by means of compound winding, some means had to be provided to counteract the results of a fall in speed of the combination necessary to allow the fly-wheel to give up its store of energy. All the known types of regulating apparatus designed to counteract the effects of irregularities of speed and load were investigated, but while these, although differing in details yet in principle designed to attain the results aimed at, by varying resistance in the field circuit of the main generator, might have been quite satisfactory in ordinary cases, they were deemed insufficient to ensure a steady voltage under the more exceptional conditions.

The combination eventually designed can be seen in Fig. 5, Plate 1, and consists of a specially arranged high-speed engine of the triple-expansion type, capable of developing about 450 b.h.p. as a normal load, when running at any speed between 320 and 375 r.p.m. Direct-coupled to the crankshaft of this engine is a continuous-current main generator, capable of generating current at a constant voltage irrespective of speed and load; this generator, which has a normal output of 340 e.h.p., with a considerable overload capacity, is used for supplying power to the ordinary dock appliances. The requisite voltage regulation is attained by means of a small machine, which is belt-driven from the main shaft, and the satisfactory results of this system are evident from Fig. 6, which is a voltage diagram, taken under ordinary working conditions. The end of the main generator shaft remote from the engine is extended to take a special flexible coupling, by means of which it is coupled to the fly-wheel shaft, on which is mounted the fly-wheel and two coal-hoist generators. In designing the plant, it was intended that the storage of power in the fly-wheel should be such that, with both hoists working with full load and to full height, the average demand from the engine should not exceed its normal rated power. By trial it was ascertained that these conditions were fulfilled, and that, even with the main generator loaded to about 63 per cent. of its normal output, in addition to the hoists working as above, the demand only slightly exceeded the normal output of the engine with a drop in speed of the combination of about 20 per cent.

FIG. 6.

Voltage Diagram during two minutes under Working Conditions.



The fly-wheel is entirely enclosed in a cast-iron case, the object of providing this being that, should the power required to maintain the fly-wheel and two hoist generators at normal speed prove excessive, the former could be run in vacuum, but, as the power required was only about 20 e.h.p. when running at the maximum speed of 375 r.p.m., the installation of the necessary gear for producing the vacuum was considered quite unnecessary, although experiments were made to determine what the saving would be. Of course, the above power is only consumed when the coal-hoists are in operation, and, under ordinary working conditions, considerable economy is effected by disconnecting the fly-wheel by means of the special clutch referred to above, when the engine and main generator run as an ordinary generating plant.

Two of the plants as described above are at present installed, and foundations provided for a third, which is now in course of construction, and for times of light load and for week-ends a direct-coupled set of 120 k.w. is provided. A small direct-coupled steam-driven exciter furnishes the necessary excitation current. An overhead travelling-crane, capable of lifting 20 tons, runs the whole length of the engine-house. A neat and compact cabling arrangement is formed by running the cables from the generators in the basement under the engine-house floor to the main switchboard, which is fixed on a gallery, and consists of 20 panels of enamelled slate, on which are mounted all the switch-gear and measuring apparatus, with the exception of the hoist change-over switch-gear, which is erected under the switchboard gallery, and by means of which it will be possible to connect any one of the four coal-hoists to any one of the six coal-hoist generators.

Coal-Hoists.—At present there are two coal-hoists, each being of the high-level and fixed type, so arranged that the loaded wagons are run on the tipping platform at the quay-level, raised to the required height and tipped, after which the empty wagon is lowered to the high-level inclined viaduct, leaving the hoist at a height of about 17 feet from the ground, and gravitating to the siding, the cradle then being lowered to the ground-level to receive the on-coming loaded wagon.

Hoist No. 1 is fixed on the East Quay of the Outer Basin, and No. 2 on the North Quay of the Inner Basin, No. 1 being suitable for lifting to a height of 50 feet and No. 2 to a height of 60 feet. Both hoists appear in Fig. 7, Plate 2, but Fig. 10, Plate 3, which is a general view of Hoist No. 1, gives a better idea of the construction. Each hoist is capable of raising, tipping, and lowering wagons carrying 20 tons of coal, with a gross weight of 32 tons, as well as those of the ordinary type at present in use holding 6 tons and upwards.

It is always expedient to decide the working speeds of dock appliances in relation to the complete cycle of operations of which they form a part, but this is particularly so in the case of coal-hoists, as so many operations are involved in addition to the actual hoisting of the load that a high speed of hoisting, which, while causing a considerable increase in the first cost of the machinery, and also in the power required for working, does not result in a corresponding high rate of coaling, unless it is possible to deal with the other operations—such as disposal of coal in the ship, getting into position of the loaded wagon, and the running off of the empty wagon, so expeditiously that advantage can be taken of a high hoisting-speed.

After careful consideration of the cycle of operations necessary to ship the maximum quantity of coal under the system of coaling generally in vogue at docks on the Clyde, where end-tipping wagons are used, it was decided to adopt a mean hoisting-speed, allowing for acceleration and retardation of about 100 feet per minute with full load, corresponding to a time of 30 seconds for the full height of 50 feet; this speed, with a full unbalanced load and a combined mechanical and electrical efficiency of 72 per cent., being equivalent to about 300 e.h.p. in the motor.

Perhaps the most difficult motion of a coal-hoist to deal with electrically is the tipping, as this has to be accomplished very expeditiously through a comparatively short distance, usually a maximum of 45°, and with a degree of accuracy very difficult to attain under such varying conditions and loads. It is always necessary to accelerate quickly, and sometimes to stop suddenly and thus give such an impetus to the material being shipped, that it will leave the wagon without sticking. Frequently this motion has to be repeated through small angles of travel several times before the whole of the material leaves the wagon. To tip the full wagons to a maximum angle of 45° in six to nine seconds requires power almost identical to that for hoisting, so that the motors for the two motions are duplicates.

From Fig. 10, Plate 3, it will be seen that the design of the structural work and arrangement of shoot, jib-cranes, and other auxiliary apparatus is on usual lines, the essential difference being that all the gearing is at the top of the structure, which has been designed to carry this additional weight. It is not proposed to describe the general structure of the hoist at length, but a brief description of the machinery, a general view of which is shown in Fig. 9, Plate 2, and its auxiliaries will no doubt be of interest. As mentioned already, separate motors are employed for the hoisting and tipping motions. The hoisting motor drives, by means of an elastic coupling and also an ordinary jaw-coupling, a pinion which engages with a spur-wheel upon the countershaft, this spur-wheel and pinion running in a cast-iron casing. At each end of the countershaft a pinion is fixed which engages with the spur-wheels firmly fixed to the hoisting drums, the drums being so arranged that the ropes go directly to the cradle without the intervention of guide-pulleys. The whole of the gearing, with the exception of the motors, is erected upon a cast-iron bed-plate to obviate errors in erection, and both motors are mounted upon one base-plate, which is bolted to the gearing base-plate. For the purpose of taking up the slack of the tipping rope during the raising of the platform, a third drum, of barrel shape towards one end, is connected to one of the hoisting drums. The tipping motor is a duplicate of that for hoisting, and the gearing generally is similar, excepting that only one drum is employed.

In view of the heavy loads to be dealt with, and the precision with which the cage and tipping cradle have to be brought to a stop at any predetermined position, the brake-gear is of great importance. The brakes for both hoisting and tipping are of the friction clinch type, the brake-bands being kept tight during the hoisting, and the clinches revolving freely in the hoisting direction. By this means the load is held in suspension immediately power is disconnected from the motor. In lowering, the brake-bands are released by electro-magnets in the usual way. Due to the fact that the hoisting and tipping motors are duplicates of each other, it has been possible to provide a simple arrangement by means of which one motor can work both motions in case of breakdown to either motor, thus enabling coaling to be proceeded with and avoiding any serious delay in the departure of a vessel.

By the special relation between the generating plant and the motors on the hoists, a very simple control arrangement is possible. The whole of the control is arranged from the attendant's cabin situated near the top of the hoist, a general view of which is seen in Fig. 8, Plate 2. As can be seen from the illustration, there is only *one control-lever*, which works in a quadrant or frame, and, by moving this lever in the various positions, the attendant has control of the hoisting, tipping and jib-crane, the only other controller being a small one for controlling the sluing of the jib-crane. Gearing is arranged in connection with this control-lever frame, which automatically renders it impossible for any of the motions to exceed their predetermined efforts, and it is also impossible for the attendant at starting to move the lever at such a rate as to accelerate at too great a speed and consequently throw an undue load upon the generating station. In fact, at all points of possible danger, the automatic adjustments come into operation, and prevent any damage from error of omission or commission on the part of the attendant. In actual working it has been found that the control is so perfect that the cradle and tipping platform can be brought to rest quite smoothly at any desired position. The wagons while on the hoist and when being run off are thus protected from the rough usage to which they are frequently subjected during coaling operations.

Capacity.—In Table 1 (page 18) the specified cycle of operations are tabulated, and these were obtained at the official trials. Comparing these with the results tabulated in Table 2 (page 18) which were obtained in February, 1909, after two years' working, it will be seen that the time required for coaling through the cycle of operations is considerably shorter.

Efficiency.—At the official trials in May, 1907, which were taken when the hoists had done practically no coaling under actual working conditions, the following readings were taken upon Hoist No. 2 :—

Total unbalanced load	32 tons 0 cwt. 1 qr.
Height lifted	60 feet.
Time hoisting	36 seconds.
Speed of hoisting	100 feet per minute.
H.P. due to load	217·3 load h.p.
Current	500 ampères.
Voltage	450 volts.
Electrical horse-power	301·6.

TABLE 1.

Details of specified Cycle of Operations.	Gross Weight.		
	Tons $16\frac{5}{20}$	Tons $18\frac{16}{20}$	Tons $28\frac{5}{20}$
	Sec.	Sec.	Sec.
Securing wagon on cradle and raising to a height of 50 feet	33	33	33
Tipping loaded wagon	7·5	7·5	9
Lowering platform with empty wagon to cradle chamber	7·5	7·5	9
Lowering cradle with empty wagon to high-level viaduct	24	24	24
Uncoupling and running wagon off . . .	14	14	14
Lowering empty cradle from high-level viaduct to ground	14	14	14
Total time per cycle . .	100	100	103

TABLE 2.

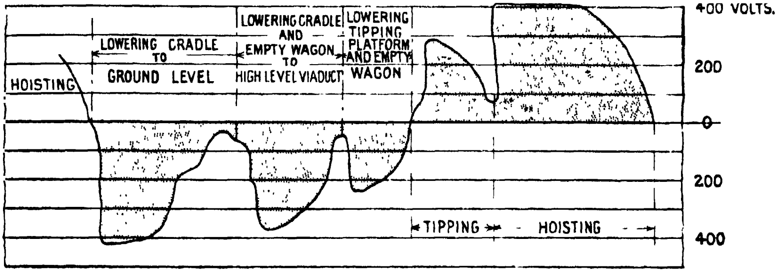
Details of actual Cycle of Operations.	Gross Weight.		
	T. C. Q. 16 5 2	T. C. Q. 18 6 0	T. C. Q. 28 3 0
	Sec.	Sec.	Sec.
Securing wagon on cradle and raising to a height of 57 feet	30	30	31
Tipping loaded wagon	8	8	9
Lowering platform with empty wagon to cradle chamber	6	6	6
Lowering cradle with empty wagon to high-level viaduct	24	24	24
Uncoupling and running wagon off . .	8	8	8
Lowering empty cradle from high-level viaduct to ground	12	12	12
Total time per cycle . .	88	88	90

These readings show a combined efficiency of 72 per cent., which figure is within that guaranteed by the contractors.

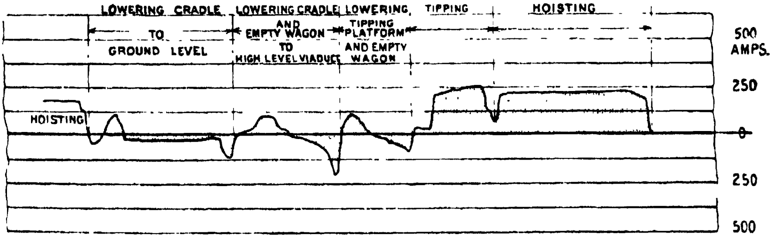
During the coaling of a ship on the 10th February, 1909, particulars of which are tabulated in Table 3 (page 20), several ampere and voltage diagrams were taken. Fig. 11 is a typical example of these diagrams, and represents a complete cycle with a wagon of gross weight of 16 tons 17 cwt., containing a net weight of coal of 10 tons 10 cwt. From the hoisting curve the efficiency of hoisting can be calculated.

FIG. 11.

Voltage Diagram of one complete cycle of operations in one minute.



Current Diagram during the same cycle of operations.



Gross load	16 tons 17 cwt.
Speed of hoisting	92·75 feet per minute.
H.P. due to load	106 load h.p.
Current	225 amperes.
Voltage	440 volts.
Electrical horse-power	132·7.

TABLE 3.

Number of Wagons dealt with.	Total time of coaling.	Equivalent number of wagons per hour.	Height of lift.	Weights.			Tons coal per hour.	Time per cycle.	Total units.	Units per cycle.	Units per hour.	Units per ton.	Tons per unit.
				Gross weight.	Net weight.	Average weight of coal per wagon.							
	m. s.		ft. in.	t. cwt. qr.	t. cwt. qr.	t. cwt. qr.		sec.					
30	31 37	57	27 10	416 10 2	252 14 0	8 8 1·9	479·5	63·2	25	0·833	47·44	0·098	10·1

TABLE 4.

—	Cycles per hour.	Time per cycle.	Gross weight.	Tons of coal per hour.	Energy per cycle.	Energy per hour.	Height of lift.	Energy per ton of coal.	Cost per 1000 tons shipped.	
									Water at 9*d*. per 1000 gall.	Electricity at 1*d*. per unit.
		sec.	tons		gal.	gal.	feet	gal.	s. *d*.	s. *d*.
Newport . .	40	90	710	444	280	11,200	46	25·22	—	—
Rothesay Dock	43	84	596·8	362¼	1·104 unit	47·481 unit	46	0·131 unit	18 11	10 11

These readings show a combined efficiency of 80 per cent.

The instruments used for taking the electrical readings were *fixed in the generating station; thus the readings include distribution losses. This result shows that the efficiency of the* hoists had considerably improved during the two years' working, and, as it was obtained at half load, further clearly demonstrates the high efficiency of electricity over wide ranges of working, a condition impossible of attainment with hydraulic power, although considerable improvement in this connection has been obtained by the employment of multiple rams. This, however, is only a partial solution, depending as it does upon the discretion of the attendant as to when he should alter the number of rams. In fact, when working with wagons of varying carrying capacity and weights, as is the case on the Clyde and other places, it is almost impossible to make the necessary adjustments at every position for the most economical working, whereas electricity quite automatically adjusts itself to the varying conditions.

Working Results.—Due to the above, and the other inherent advantages of electricity in actual working, the results obtained have been most satisfactory, and compare very favourably with hydraulic hoists, notwithstanding that the conditions of working up to the present have not been conducive to the most economical results. Particularly is this so as regards the size of wagons, as, although the hoists are constructed to deal with the largest wagons which will eventually come into general use, only comparatively small ones, and those of widely differing carrying capacity, are at present available.

The total coal and other material shipped by the two hoists during twelve months was 556,419 tons. The units consumed during this period was 80,164, and the number of wagons dealt with 70,604. During this period as much as 23 tons of coal per unit have been shipped, while, including all distribution losses and also the power necessary for the working of all auxiliary apparatus on the hoist, including the jib-crane, adjusting of shoot and shoot point, etc., the current consumed over the whole period only averaged one unit per 6·94 tons of coal shipped. As emphasizing the adverse conditions under which the hoists are at present working, it will be noted that 70,604 wagons were handled in shipping 556,419 tons of coal, or an average of only 7·88 tons of coal per wagon.

Referring again to the coaling on the 10th February 1909, a note was taken of the speed of working under ordinary conditions, when 30 wagons were shipped into the vessel in 31 minutes 37 seconds, which is at the rate of 57 wagons per hour, the height lifted being 27 feet 10 inches, and the total weight of coal shipped 252 tons 14 cwt. Had the wagons been as large as the hoists are constructed for, the total quantity of coal shipped would have been at the rate of 1,140 tons per hour. As mentioned above, these results are tabulated in Table 3 (page 20), and, in order to enable a comparison to be made with the results obtained at Newport, and published in the Paper by Mr. Macaulay,* previously referred to, these results are adjusted in Table 4 (page 20) to an assumed height of lift of 46 feet. From this Table it will be noted that, while the average quantity of coal per lift given by Mr. Macaulay was 11 tons 2 cwt., for Rothesay Docks it was only 8 tons 8 cwt. 1·9 qr., so that electric hoists with wagons containing a similar quantity of coal to those at Newport could have loaded an additional 117 tons, making a total of 477 tons 6 cwt. per hour.

Cost of Working.—Referring to Table 4 (page 20) it will be seen that the consumption of energy for coaling by electric hoists, including distribution losses, is 0·131 unit per ton of coal shipped when working to a height of 46 feet. This at 1*d.* per unit is equivalent to 10*s.* 11*d.* per 1,000 tons of coal shipped.

For coaling by hydraulic hoists the consumption is shown to be 25,220 gallons of water, which at 9*d.* per 1,000 gallons is equivalent to 18*s.* 11*d.* per 1,000 tons of coal shipped, showing a saving of 8*s.* per 1,000 tons in favour of electricity. Some remarks are made later in the Paper with reference to the comparative cost of generating hydraulic and electric power, but it may here be mentioned that the above figure of 9*d.* per 1,000 gallons has been assumed as a fair average of the varying figures obtainable.

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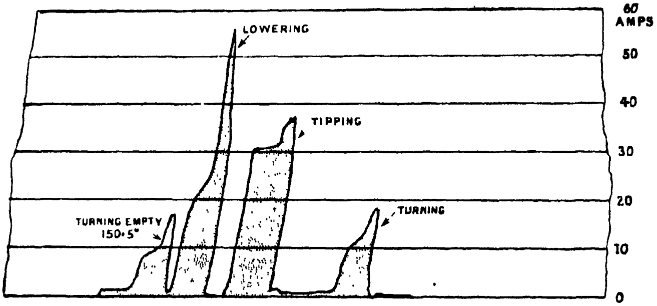
* Proceedings 1906, Part 3, page 435.

Maintenance.—The result of two years' working shows that the cost of upkeep has not exceeded, and is not likely to exceed, that required for the upkeep of coal-hoist plant operated by hydraulics or steam.

Turntables.—Where end-wagons are employed, turntables are necessary to ensure that the wagons are run on to the hoist with the end doors in the correct position for tipping. This being so, it was decided to make the turntables of the tipping type, so that the wagons can be run direct on to the hoist without the aid of a capstan. For operating the turntables two motors are provided, one for turning and one for tipping. With a maximum load of 32 tons the turntables revolve at the rate of 300 degrees in 15 seconds, and a similar load can be tipped the maximum height of 14 inches in 6 seconds, lighter loads being dealt with at proportionately greater speeds. Fig. 12, Plate 3, shows the turntable in its tipping position, while Fig. 13 shows diagrammatically the current consumed when turning and tipping wagons of the ordinary type now in use.

FIG. 13.—*Current used while operating Turntable.*

Gross weight of wagon = 16 *tons* 14 *cwt.* 2 *qrs.* Voltage = 445.



In the two turntables at present constructed, the turning motion is driven through a combination of spur-gearing and wire-rope. The design of the turntables for Hoists 3 and 4 will be somewhat modified, and, for various reasons, the wire rope and drums will be discarded in favour of spur-gearing throughout.

Cranes.—At present there are eighteen 4-ton travelling jib-cranes. Of these, the first ten erected are placed on the East and North Quays of the Outer Basin, and are of the free-barrel type, of practically the same design and make as the 3-ton crane experimented with at Princes Dock. A general view of one of these cranes is shown in Fig. 14, Plate 4, and the following are the leading dimensions :—

Maximum working load	4 tons.
Total range of lift	80 feet.
Radius of lifting rope variable	20 to 45 feet.
Projection of rope beyond face of quay	32 feet.
Centre of jib-head pulley above cope at 45 feet radius	60 feet.
Clear lift above cope of quay	50 feet.
Extreme radius of any revolving part at back of crane	9 feet 6 ins.
Clear height from cope to lowest revolving part of crane	29 feet.
Lifting speed with load of 4 tons	120 feet.
Speed of sluing at hook with maximum radius and maximum load	300 feet per min.

The carriage is constructed with an archway, having a vertical height of 15 feet, sufficiently wide for the passage of locomotives. The hoisting is arranged with double gear, and driven by a motor of 50 h.p., the drum-shaft being arranged with a coil clutch so that the gear can be disconnected from the barrel and the lowering effected without the motor or gearing revolving. The derricking is operated from the same motor by means of suitable clutches and a special controller. The sluing is arranged with worm and spur gearing, and driven by means of a 10-h.p. motor, a motor of similar power but totally enclosed being arranged for travelling.

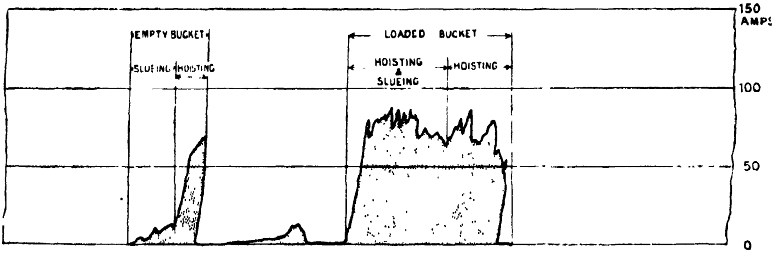
Fig. 15 shows a diagram taken with one of the cranes when unloading iron ore, with an average total load for each lift of 2¾ tons.

The other eight cranes are erected on the south side of the dock, six having free barrels and two fixed barrels.

Capstans.—One of the most necessary and at the same time inefficient appliances in connection with dock equipments is the capstan. Before deciding upon the type to be erected at Rothesay Dock, the engineers thoroughly investigated the capstan question, and, as a result of their investigations, a capstan of their own design, now known as the "Clyde" capstan, was erected at one of the Trustees' Docks as an experiment, the principal features of this capstan being that the head is not fixed to the spindle in the ordinary way, but is revolved by a clutch sliding on the upper end of the spindle inside the capstan head. The capstan is operated either by a single removable handle or by one handle and a foot-pedal. By having the head loose on the spindle, a wire-rope fixed to the head can be used and a positive pull obtained as soon as the head begins to revolve, thus avoiding the heavy power-losses incurred, more especially in hydraulic capstans, when they are revolved without doing work. Moreover, the rope being fixed, there is no slipping and grinding away action, as in the case of capstans where hemp ropes are used;

Fig. 15.—*Current used while operating Jib Crane.*

Average Load 2¾ tons, including weight of Bucket. Voltage = 415.



consequently the head will last as long as the rest of the capstan without repair or renewal.

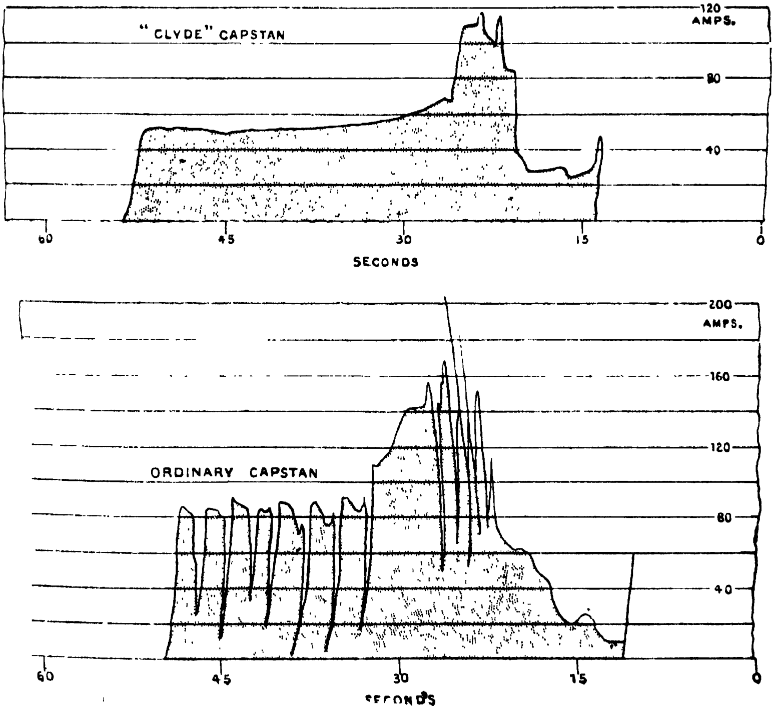
After the experimental capstan had been in use for some time, comparative trials were made with the fixed-rope capstan, and with an ordinary hydraulic capstan to ascertain their efficiencies, and the results showed that, even assuming the hydraulic capstan had a positive pull, that is, with the rope fixed on the capstan head, the efficiency with gross loads of from 12½ to 50 tons varied 10·17 to 32 per cent., and with the "Clyde" capstan for the same loads, the efficiency varied from 42 to 78 per cent. From sixty observations it has been found that the ordinary capstan with fixed head and loose rope makes an average of 3·63 revolutions for 1 revolution of the "Clyde" type of capstan, when working under identical conditions. As a further comparison a standard ordinary electric capstan of the best modern type was put down in close proximity to the "Clyde" capstan, and records taken to ascertain the current consumed in each case. The load curves of both capstans are shown in Fig. 16, and clearly indicate that not only is there an economy in the consumption of current, amounting to not less than 25 per cent., but the maximum load and therefore the maximum demand on the generating station is 50 per cent. less in the case of "Clyde" capstans as compared with other types. Briefly summarized, these comparative trials show that electric capstans offer many advantages over hydraulic capstans in that they have much higher overall efficiency, and can be overloaded to 25 or 50 per cent. over the maximum working load, while the maximum load of the hydraulic capstans is limited by the working pressure.

The advantages of the "Clyde" capstans, as compared with those of ordinary type, are: economy of power as shown by the trials; 50 per cent. reduction in maximum demand on the generating station. With the more even pull of this type of capstan there is less stress, which gives a better working condition throughout the machinery of the capstan. The same conditions also give easier conditions of work on the electrical installation throughout. Owing to the fewer revolutions run, the wear and

FIG. 16.—*Comparative Tests of Electric Capstans.*

Type of capstan	"Clyde"	Ordinary.
Number of trucks hauled	12	12
Gross weight hauled	183 tons 4 cwt.	183 tons 4 cwt.
Distance travelled	80 feet.	80 feet.
Time in seconds	38	38
Average speed . . per min.	126 feet.	126 feet.
Maximum current . amps.	116	200
Average current . ,,	54	69
,, voltage	240	240
Power in B.O.T. units	0·138	0·175
Ratio of power consumption	0·75	1

Load Curves.



tear of gearing is much reduced. The old type of capstan requires the use of one foot for the pedal and both hands for the rope; in rainy weather the man gets soaked through with the drips from the wet rope. This is obviated in the "Clyde" capstan. A large saving in cost of ropes is effected, this really being the principal object for which it was designed. From many figures obtainable it appears that the annual cost of hemp ropes for ordinary capstans is almost £15, while that for the "Clyde" type may be taken at about £1.

As a result of these comparative trials, thirty "Clyde" capstans were adopted at the Rothesay Dock, where nine of the ordinary type were already working. The working results of both the ordinary and the "Clyde" capstans have been so satisfactory that it may be claimed that the troubles hitherto connected with capstans have now been entirely eliminated. Fig. 19, Plate 4, shows the internal arrangement of the "Clyde" capstan.

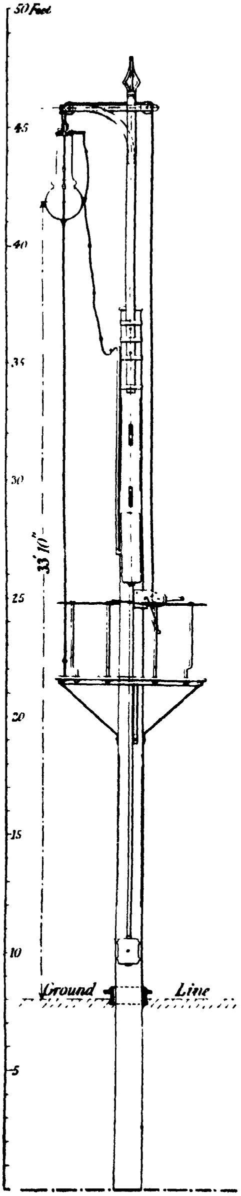
Pier-head Capstans.—Two capstans are erected at the dock entrance, one at each side. Each of these capstans is arranged with a head 36 inches high and about 20 inches diameter at the smallest part. It is geared to run at a peripheral speed of 20 feet per minute as a slow speed, a quick gear being employed to increase the speed (for hauling in the rope) to about 80 feet per minute. The motor for driving the capstan is direct-coupled to the gearing and erected in the capstan-pit, but the control-gear is fixed in a cabin in close proximity. Fig. 18, Plate 4, shows one of the capstans and control-house.

Lighting Installation.—The dock is lighted throughout by means of arc lamps arranged on wooden poles with an extension structure of wrought-iron. A platform is arranged about 13 feet up from the ground line, upon which is fixed the necessary raising and lowering gear, and the lamps are lowered to this platform for trimming. Fig. 20 shows a standard pole fitted complete with lamp and raising and lowering gear. The installation consists of 91 lamps, which are arranged in suitable circuits controlled from the generating station.

The lighting mains are, for the most part, carried under ground on the solid system, although the cable tunnel is utilized for carrying the wires for some of the circuits to a point at the south-east corner of the dock, where a suitable box is erected so that the cables run in the tunnel can be disconnected from the underground system for testing purposes. The generating station is lighted by means of a circuit of nine arc lamps, and a suitable number of incandescent lamps.

Power Distribution.—A very important matter in all electrical undertakings is the power distribution, and this is especially so in docks and similar places where heavy traffic, subsidence of ground, wet and storms have to be contended with, while personal safety, protection from damage and general convenience for making connections are essential provisions. The extensively adopted system of running cables in wooden troughing filled in with bitumen or pitch has many advantages, but it is costly and not very adaptable for making connections, special boxes and fittings being necessary. In the present case, a tunnel or culvert originally intended for water-pipes, running parallel with the quays and extending their whole length, was available, and the question resolved itself into one of whether the mains should consist of insulated cable, or bare copper strips supported on insulators. The

FIG. 20.—Arc-Lamp Post.



advantages of adopting the latter system are at once apparent on account of low first-cost and adaptability for making connections, but the experience with such systems had been so disastrous that the possibility of its adoption was approached with considerable misgivings. Having thoroughly examined the whole question, however, and ascertained exactly where trouble had been experienced, it was decided that there was no real reason why, if due precautions were taken, the system should not be successfully adopted. Special attention was given to the design of the fixtures and the insulators, with a view to the prevention of any possibility of leakage or electrolytic action. A general view of the fixtures and arrangement of cables is shown on Fig. 17, Plate 4. The fixtures are suspended from shackles in the roof of the tunnel, and consist of two vertical tubes, on which are four insulators, and upon these the cross-bars for carrying the strips rest, the top and bottom strips being of opposite polarity. Conductors of one polarity are supported on a separate insulator, while those of the other polarity are carried in grooves on one insulator. This is necessary to prevent electrolytic action, and for the same reason the insulators differ in the material of which they are composed. The insulated cables seen above the bare conductors are for the hoists; the small lighting cables can also be seen carried on insulators.

The total length of the subway is approximately 1⅛ mile, the greatest distance from the station being ¾ of a mile, and the total length of bare copper strip employed is equivalent to 8¼ miles of single strip.

The connections to crane-boxes, capstans, etc., are made by bolting a cable lug on the distributor, from which the cables are laid on the solid system, these connections being chiefly in a straight line, and not averaging more than a few feet in length, so that should a fault develop it can be readily located. In addition to the ease of making new connections, the system itself is extremely flexible, as the "feeders" can be coupled in at any desired point on the distributor, thus rendering it possible to so adjust the current in each feeder as to ensure an even drop in voltage over the whole system. While not claiming that this system is a cure for all the evils that beset distribution schemes, the results of working in the present case have been such as to prove that, when properly installed, it is flexible, reliable and comparatively cheap, the saving effected in this instance being several thousands of pounds. No fault in the tunnel or on the solid system of sufficient magnitude to cause a stoppage has occurred since the commencement of working, notwithstanding that, although it was expected that the tunnel would be quite dry, and every precaution had been taken to render it so, water still finds its way in, and renders the tunnel extremely damp at some places.

Working Costs.—As mentioned in an earlier part of this Paper, full working records are not yet available, but there is every reason to anticipate that, with the dock completed and working at full capacity, when the annual consumption will be approximately 1,500,000 units, the total cost to produce this amount of energy, including works-costs and capital charges, will be under the estimated figure of 0·94*d.* per unit, this view being confirmed by taking as a basis the figures already ascertained. It was estimated that approximately 600,000 units per annum would be required to operate the first portion of the dock, and that the works-costs, including coal, water, stores and oil, wages, repairs, etc., to produce this amount of energy would be 0·9*d.* per unit. The actual works-costs are, on an average, with a consumption of approximately 560,000 units per annum, approximately 0·89*d.* per unit. Taken over periods during which the dock was busy, and consequently more units being generated, these costs were in the neighbourhood of 0·6*d.* per unit. The capital charges at present increase the above figure of 0·89*d.* to approximately 2*d.* per unit, but, of course, in the incompleted state of the dock these capital charges are out of all proportion.

It would be interesting to make a comparison on this basis with corresponding costs for hydraulic power, but, unfortunately, all records available are so widely divergent that it is difficult to obtain a reliable figure. The figures obtainable, varying from (say)

2*d*. to 1*s*. 9*d*. per 1,000 gallons at a pressure of 750 lb. cannot obviously be on a common basis, but in any case the fact must be recognized that, whereas the supply of electricity to any given quantity of work is a direct measure of the work done, the supply of water, in the case of hydraulics is always more than the quantity required, and therefore some of it is wasted; this waste may vary from 5 to 50 per cent.

It has been shown in an earlier part of the Paper that, under conditions particularly favourable for hydraulic power, the cost of shipping 1,000 tons by electric power would be 8*s*. cheaper than by hydraulic power. This figure is eminently satisfactory, particularly in view of the fact that, when deciding to adopt these coal-hoists it was not anticipated that the cost for shipping coal would be below that of hydraulics, the object being to have available electric coal-hoists which would be as reliable in working as hydraulic hoists, and so secure the advantage of having the whole of the dock electrically equipped.

General Conclusions.—This Paper was commenced with a reference to the Proceedings at a Meeting of the Institution of Mechanical Engineers, and will be brought to a close with an allusion to a Conference of a kindred Institution. In an admirably compiled Note, Mr. Squire, at the Conference of the Institution of Civil Engineers, held in June 1907, inaugurated a discussion on "Dock Equipment, including the Relative Advantages of Electric and Hydraulic Appliances." The discussion elicited the opinion of many speakers of eminence in the dock engineering world, who almost unanimously expressed dubiety as to the satisfactory application of electricity to certain classes of dock machinery, which sentiment was well summarized by the Chairman, Sir William Matthews, when he said: "There are, however, certain general principles which we may go upon. The first is this—one of those laid down by Mr. Squire in his Note with regard to the actuating of dock-gates, sluices, capstans, coal appliances, and other machinery of that kind, that at the present time at all events hydraulic machinery is pre-eminent for such work." These remarks were made three years ago, and were doubtless quite a fair résumé of the position at that date, but it is interesting to review them at the present time in light of the results obtained during about three years' working of Rothesay Dock, where electric power has been successfully applied to some of the very appliances referred to by Sir William Matthews and other speakers as not being adaptable for this power. In doing so, it will be more convenient to divide the more important points under different headings, and as reliability is the key-note of all dock machinery that will be dealt with first.

Reliability.—At Rothesay Dock, where electric power alone is available, and where coal-hoists, cranes, capstans, turntables, and other machinery are in constant operation, no stoppage, due to electrical causes, has occurred to interrupt the regular working of the dock. The various docks on the Clyde being tidal, dock-gates and sluices are not required, but the successful application of electrical power to swing and rolling-lift (Scherzer) types of bridges, the uninterrupted working of which is essential, clearly demonstrates the reliability of electric power for such work. If any additional testimony to the mechanical strength and reliability of electrical plant is required, it is to be found in the many thousands of horse-power installed to operate rolling mills, than the demands of which nothing can be more severe.

Economy.—It is admitted that where cranes are working under ideal conditions for hydraulic power—that is, at full load—there is nothing to choose between the systems, but as these conditions are rarely or never met with in actual working, the advantage is with electric cranes. Electric coal-hoists have been shown to be more economical than hydraulic hoists, and electric capstans much more so.

General adaptation.—It has been suggested that in order to secure the advantage of adopting the power best suited to the appliance operated, a dock might be equipped with a combination of both forms of power, but obviously such a compromise has many objections, and it would appear quite unnecessary, since electric power has now been proved to be quite reliable and economical for working all dock appliances, a feature not possessed by hydraulic power. This, together with the fact that the current for lighting is also produced by the electric plant, results in a better load-factor, and a consequent reduction in generating cost.

Storage of Energy.—It has always been charged against electric power that the system possesses no equivalent to the hydraulic accumulator, the main function of which is to equalize the demands upon the power-station that a comparatively small prime-mover may be employed. The plant at Rothesay Dock consists of an entirely new combination, arranged by the authors for the first time, in which an engine of 450 h.p. normal rated output supplies power for an aggregate of 936 h.p. in the generators, which power is utilized for all requirements of power and lighting.

Cost of Generating Station Plant.—It is difficult to form a comparison under this head, as the design and equipment of each station has to be arranged to suit local and other conditions. It is probable, however, that there need be no appreciable difference in the capital cost of an electric and hydraulic station when fully equipped for the complete dock installation of power and lighting.

Power Distribution.—The initial capital expenditure for the distribution system is probably about the same. Whatever the life of hydraulic pipes may be, that of an electric system as installed at Rothesay Dock will be as long and the scrap value considerably more.

Fire Risks.—The risk of fire with hydraulics is, of course, non-existent; with a properly installed electric system it may also be regarded as practically so.

Finally.—Summarizing these conclusions, the authors submit that they have by this entirely electrically-equipped dock shown that, apart from the admitted advantages of electric power, the relative position of electric and hydraulic power is now :—

(1) Electric and hydraulic systems are equally reliable ;

(2) The cost of working with electric and hydraulic power is equal at full load, but under variable and low load conditions electric power is cheaper ;

(3) Electric power has now the equivalent of the hydraulic accumulator ;

(4) Electric power can be applied to all dock appliances, and has greater flexibility than hydraulic power.

In conclusion, the authors wish to thank the officials of the Clyde Navigation Trustees and their Assistants for their ready co-operation at all times ; Mr. D. Fyfe, Mechanical Engineering Assistant to Mr. Baxter, and more directly to Mr. Frank Anslow (who is partner with Mr. Dixon) for his assistance in the designing and carrying through of the equipment, and in the preparation of this Paper.

The Paper is illustrated by Plates 1 to 4 and 7 Figs. in the letterpress.

Discussion on Friday, 20th January 1911.

The PRESIDENT said the authors had lost no time in putting the results of their valuable experience before the Institution and putting it in a very interesting way, and he thought the members were much indebted to them. He therefore asked that the heartiest vote of thanks should be carried to them for having sent the Paper to the Institution.

The motion was carried with acclamation.

The President said there were present that evening a number of people who were interested in the production of hydraulic machinery, and others who were interested in electrical machinery, and therefore there ought to be an extremely good discussion. He could not help being reminded of the fact that in 1895 his friend, Mr. Ellington, was reading a Paper at Glasgow, he believed, on the hydraulic equipment of that city, and pointed out what a convenient thing it was to have hydraulic power for doing work, because it was known that 2 gallons of water per minute at 750 lb. to the square inch equalled 1 horse-power. Mr. Ralph Hart Tweddell, who was in the room at the time, quite agreed with Mr. Ellington, but said he thought his system was much better because 1 gallon of water at 1,500 lb. per square inch equalled 1 horse-power.* He himself (the President) ventured to add a third calculation. In the North of England they purchased pressure-water at 1,000 lb. per square inch, and 2 gallons of water at 1,000 lb. per square inch in 1 minute was 1·333 h.p. Using that for 60 minutes instead of for 1 minute gave 1 horse-power-hour. As was well known, a Board of Trade unit was 1·34 h.p. for one hour. Therefore 1,000 lb. per square inch, if used for one hour, practically gave the equivalent of a Board of Trade unit. If a man required 2 gallons of water at 1,000 lb. per square inch each minute for 60 minutes he was using 120 gallons, and if, as in the North, that water could be purchased in quantity at about 1*s.* 6*d.* per 1,000 gallons, it would work out to 2·16*d.* per 1 Board of Trade unit. If electric current could be purchased at 1*d.* per unit, and it was compared with pressure water at 1,000 lb. per square inch, pressure water at 1*s.* 6*d.* per 1,000 gallons cost about twice as much as electricity. Of course, that did not deal with the whole of the case.

Those who were going to discuss the Paper that evening would each have his own say as to the wear and tear and as to the first cost of apparatus, but he wanted, in connection with another branch of the Paper, to draw the authors' attention to the fact that they had put in new hoists at the Rothesay Dock rather than coaling-cranes.

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* **Proceedings, 1895, Part 3, page 385.**

Now it was a curious fact that coaling-cranes, when dealing with certain classes of ships, taking cargoes of from 1,000 to 1,500 tons of coal, not large ships, with somewhat restricted hatches, in a dock which was crowded, and where they could not always be shifted quickly so as to bring one hatchway after another under the coaling appliances—ships that did not give the advantages such as the great vessels gave that went into Cardiff and had four hoists working coal into them at once—under those circumstances there were a certain special set of conditions in which certainly the crane was better than the hoist. As illustrating that point he might say what happened in one port with which he was very familiar where between one and two million tons of rail-borne coal were shipped per annum. By dividing the 24 hours of the day and carefully observing, during a period of three or four months what was done by the hoists and what was done by the cranes, it would be found that a large proportion of the time was occupied in doing other things than actual tipping. In the case of both sets of appliances about 15·75 of the time was occupied with meal hours, which time was not remunerative so far as the appliances were concerned. In the case of the hoists 53·49 per cent. was occupied in tipping; waiting for ships came to 8·24 per cent.; waiting for coal—the manipulation of the wagons backwards and forwards—1·14 per cent.; adjustment of chute, 3·07 per cent. The adjustment of the chute was a thing that always had to be done with a coaling-hoist, the chute being adjusted as the ship went down into the water with the addition of the load, and the loss of time was 3·07 per cent. in making the adjustment. Then there was the swinging and changing of the ship from end to end in order to bring the hatchway immediately under the hoist, an operation which consumed 4·89 per cent. of the time. The worst thing of all, however, was the trimming, which took 12·25 per cent. of the time. The other causes, trivial as they might be, came to about 1·17 per cent. He believed if he had read them all, the total amounted to 100 per cent. of the time occupied by coal-hoists, Table 5 (page 38). The measure of the amount of work that could be done by any coal-hoist at any port was the rate of speed at which the coal could be

(The President.)

trimmed in the vessel, and taking the figures for a crane it would be found that waiting for ships in the particular case he was mentioning *was 5·04 per cent.; waiting for coal, 1·38 per cent.*; adjustment of *chute, nothing—there was no chute, representing a considerable saving in time*—swinging and changing 3·88 per cent.; trimming in holds 8·24 per cent.; meal hours 15·28 per cent.; and other causes 1·99 per cent. Now, comparing the two appliances for the time actually occupied in tipping and handling and doing the work of putting the coal on to the boat, in the case of the hoists it was 53·49 per cent. of the time, and in the case of the crane 64·19 per cent. So that there was a clear gain of about 11 per cent. in favour of the crane as against the hoists. One of the reasons for that was that when a wagon was lifted up by a crane, it formed its own chute; it was lifted at an angle and the coal tipped straightforwardly under the coamings of the hatch, or the wagon could be swung round and the coal tipped forward, or swung round in another direction, and the coal put directly under the hatches on the other side. In that way the crane turned out to be a very much more rapid working appliance, and because of its easy adjustment, meant less breakage of the coal.

TABLE 5.

Test of Three Months' Work, showing Percentage of Time occupied in each kind of Operation.

—	Two Hoists Combined.	Two Cranes Combined.
	Per cent.	Per cent.
Tipping and Handling . .	53·49	64·19
Waiting Ships	8·24	5·04
Waiting Coal	1·14	1·38
Adjustment of Chute . .	3·07	—
Swinging and Changing . .	4·89	3·88
Trimming in Holds . .	12·25	8·24
Meal Hours	15·75	15·28
Other Causes	1·17	1·99
	100·00	100·00

Colonel F. W. **TANNETT-WALKER** said that as one who was present that evening, not as a member of the Institution but as a guest, he wished to say that he felt it a privilege to be allowed to open the discussion. He noticed the authors said that they specially provided an electric crane with the view to trying it in parallel working with a hydraulic crane. One could readily imagine that the electric crane was the best they could buy, and he would like to know if one of the best makers of hydraulic cranes at that particular moment had had an opportunity of providing for the Clyde Navigation an equally modern and equally capable hydraulic crane of the same size. The general impression of hydraulic people was that the best electric crane that could be made was compared with a very old hydraulic one.

With regard to capstans he would like to ask Mr. Baxter if the capstan referred to actually cost £70, or something between £200 or £220. According to the speaker's reading of the Paper, the record of the electric tip was 30 wagons in 30 minutes. It did a wagon a minute for 30 minutes, but there was nothing in the Paper as to its doing a wagon a minute for more than 30 minutes, and he would like to know if such a record had been made. According to the authors, there was no advantage in exaggerating the speed of lifting, and a speed of 150, 180, or 200 feet a minute, the speed at which hydraulic engineers now worked, was useless, and that an average of 100 feet was all that was necessary owing to the other obligations of the cycle to mark time. He would like to ask the President if, when the Great Western Railway set off to run from Paddington to Plymouth in four hours, or the Midland or the Great Northern set off to run from Leeds to London in 3½ hours, they first settled what would be a reasonably good speed to go over the crossings and through the stations, and then settled that that was the speed for the journey. Of course, the speed at which they ran was not the average, but the speeds made the average, and they went at all the speed possible when the line was clear for it. When there were thousands of tons of coal on the sidings to be got into a ship, a wise man would put it into the ship immediately the hold was empty, and he was going to give figures presently as to what had been done in that way.

(Col. F. W. Tannett-Walker.)

The electric tip was described as being fitted with brakes, and apparently worked very smoothly, but he saw in the brake and in the tipping gear, which the authors acknowledged was the problem, the greatest difficulty and the greatest fault that could be found in that particular tip. It might be a fact that it was possible with the brake to stop the cradle as it rose exactly where it was required to stop with great smoothness and precision and then tip it; but then one did not want to stop it. When tipping into one kind of ship it was necessary to lift the cradle, and, on reaching the place, the lifting and the tipping should go on at the same time. If it was a high-level tip and the cradle was being lowered, as soon as a suitable place was reached the tipping should go on with the lowering; it was not necessary to stop and then begin to tip, which meant a loss of 15 to 18 seconds in the tipping. The tipping ought only to occupy 2 or 3 seconds, and 2 or 3 seconds subtracted from 15 or 18 left a good deal out of the minute. He noted that the authors said the tipping was their problem, and he submitted to them that it was not solved by the tips at Rothesay Dock. The problem could only be solved by that bump which was given to tipping gear and which received the name of the " kicker " amongst the workmen. The most careful investigation had shown that if there was the kick, the material would go out at an angle of 40°, but if the kick was absent, there was considerably more difficulty; in fact, the coal would go out at an angle of 40° much better with a kick than it would at 60° without the kick. He was sure the engineers of the North British Railway had had that experience.

Comparison was made in the Paper between electric and hydraulic machinery, and the comparison was made with the Newport hydraulic tips. Hydraulic engineers, however, did not consider that they were really quick tips, and he would give figures quite different from those in the Paper upon which the comparisons were based. If one wished to see quick tipping, one must go to Penarth, the Albert Docks at Hull, and to the latest tips of the Great Western and Midland Railways at Swansea. It was claimed that the dock was completely equipped by electric machinery, and he thought there must be some slight misunderstanding, because the greatest problems of a fully-equipped dock were the gate-machines and sluices. The Rothesay Dock was really not a dock; it was a tidal riverside quay, with no big gate-machines requiring huge rams to push them in and out, and therefore there were none of those great demands on their pumping plant.

With regard to the fly-wheel as opposed to the accumulator, it was suggested that the problem was solved by the fly-wheel. He did not believe himself there was a better apparatus than a fly-wheel, and personally he had had the best possible results by putting in at large works fly-wheels on different parts of shafts where very sudden burdens came upon the shaft, as, for example, in plate-bending rollers. Therefore he held no brief against fly-wheels; he thought they were extremely good things. But he wanted to show what had to be put in the place of a fly-wheel to accomplish the storage necessary in a coaling dock. The Barry Dock had not very modern machinery, but he referred to it as a dock about which he knew something, because his firm had supplied the bulk of the machinery. The horse-power of the Barry Dock accumulators was 4,000. Where was a fly-wheel that would give 4,000 h.p.? In the accumulators, 4,000 h.p. was stored up for use at any moment. At Barry Docks there were thirty tips, not two. The ships did not come when they were asked for, but they came when the weather and the tide brought them, and they all wanted to be loaded with coal at once. Therefore thirty tips had to be used, and 4,000 h.p. was the actual storage. In other words, there were 17 casings, each holding 100 tons of stuff or something like that, 26 feet up in the air, and all waiting to be of assistance when a ship was going to be coaled. The engine could go plodding on under the most economical conditions and at a busy time another engine could be started, and then another, until the whole of the nine engines were working; there was always 4,000 h.p. to come on at any moment, and it did not cost a penny except the £1,000 for the accumulator and the packing of a gland about once a year. Those were plain figures which he thought could not be disputed.

With regard to the multiple rams referred to, he did not think there was any particular objection to them if reasonably carried out.

(Col. F. W. Tannett-Walker.)

There were arrangements in modern tips by which the multiple rams brought no complication into the lever arrangements of any kind.

With regard to the work done, he had noticed that there were 278,000 tons of coal shipped in twelve months by one tip, and he thought that that was the problem that he had to deal with in the discussion. On looking into the question as to what other tips were doing, he found that all tips did at least that, even if they were the old wooden balance-tips without any hydraulic machinery or electrical machinery at all. It was only 32 tons an hour taking the whole year. That was not the problem. The problem was a traffic problem. The ships came in with a tide, and it was necessary to deal with the coal, if possible, before the next tide took the ships out. Therefore 278,000 tons were absolutely nothing. The Taff Vale, the Swansea, the Great Western, the North-Eastern, and the North British Railways did about 400,000 tons, but he made no point of that, except to say that the work was done. The Barry Docks put 4,000 tons into one ship in 6½ hours with two tips. In the face of that, who could say that coal must not be tipped quickly because the trimmers could not take it? The same railway company had informed him that day that they were repeatedly putting in 4,000 tons in less than 12 hours with one tip. The North-Eastern Railway at Hull had put, within quite a recent period, with a plain water-hoist, 2,886 tons into an inconvenient, small ship, not a self-trimmer, between one tide and another. All the haulage to the quayside, the mooring, the putting of the ship into place, the adjusting of the chute, etc., were finished within twelve hours, and the ship had gone with 3,000 tons of coal. Another kind of example was even more illuminating, as showing what could be done when a ship came alongside if the means were there to do it. Mr. Stirling, of the Hull and Barnsley Railway, informed the speaker that his two hoists put 840 tons on board in an hour. The only conclusion he could come to was that there were better trimmers in Yorkshire than the trimmers mentioned by the authors, and that seemed to be the only solution to the problem.

With reference to maintenance and the relative economy of working, the authors maintained that "It has already been proved to be so and so." He contended that it had not been proved, and he would take the authors' own figures. They really asked the members to acknowledge that it cost 9*d.* a thousand gallons to pump hydraulic pressure. It did not, and need not cost half that sum. Why could not men be mechanical engineers; why dub themselves hydraulic engineers and electrical engineers instead of calling themselves mechanical engineers right out? Why should not the mechanical engineer have the same highly expansive, beautifully made triple engines to drive hydraulic machinery as the electrical man has to drive his dynamo? Mr. Ellington had been making economical engines for years, and his (the speaker's) father had made compound surface condensing highly expansive engines forty years ago. The hydraulic machinery manufacturers had made a serious mistake: in response to demand they had made plant of a cheap kind. If hydraulic engineers would do all they possibly could —his own firm had done it for some time now—to make better plant and not cheaper, to use every appliance in the boiler-house, in the engine, and in the mains, in the packing of the glands and the turning all the rams parallel, making everything as good as it could be made, then hydraulic manufacturers would be able to stand shoulder to shoulder with the electrical engineers. There was no difficulty in producing power at 2*d.* or 3*d.* a thousand gallons. He did not think himself that Mr. Macaulay's figure of 2*d.* was reasonable, as he added nothing for capital expenditure, but at 3*d.* to 4½*d.* there was not the least difficulty. Instead of taking the hydraulic pressure at 9*d.* it should be taken at 3*d.*, and then the comparison made with electrical machinery. The people who were best for both hydraulic and electrical work were those who would allow a good job to be made; and he thought it would be found that hydraulic machinery would show figures which would persuade the authors to postpone their jubilation for another five years, and to think there was something still in plain straightforward hydraulic machinery, in which any leak could be at once shown by the splashes that came out. If the authors would only wait that five years, he was of

(Col. F. W. Tannett-Walker.)
opinion they would find that hydraulic engineers did not belong to the class of people who simply blew the organ, but were people who could make a capstan or a crane, and certainly he claimed that up to the present they were the only people that had ever made a fast coal-tip that could put in a wagon a minute whatever the size of the wagon.

Mr. WILLIAM H. PATCHELL, Member of Council, said he did not care whether it was steam, electricity, or hydraulics, an engineer nowadays had to have each as a tool in his basket, and he was not wise if he tried to use one tool for everything. He was glad to see that the authors, in settling the size of their hoists, had taken 32 tons. A good deal of his own work had been done in South Wales, and it was only within the last few months that the 8-ton wagon had been stopped. It was really ridiculous to see the amount of sidings required and the comparatively small amount of coal on the sidings due to the waste of buffer space. In some of the old docks it was impossible to alter the existing tips except at heavy capital expenditure, but for new work he was glad to see that 30 tons was taken as the unit. He did not know that the authors had made out their case for putting down their own power-station, as they did not give quite enough information about the outside supply available. In most districts now electricity was given away—possibly at the Rothesay Dock it was still happily charged for to the benefit of the shareholders or the ratepayers. In the South of England, and he believed in the North East, it was given away at rates which would render a power-station for intermittent use prohibitive.

With regard to plant the authors did not say very much, and stopped short at some interesting points. They had used a triple-expansion engine, but he would have thought for such varying work the low-pressure cylinder would have been a "passenger"! Probably a compound engine would have given equal economy in fuel at a less capital cost.

In dealing with the question of the fly-wheel they did not give any technical details of the fly-wheel itself, although they claimed that it was the equivalent of an accumulator. It could not be a large fly-wheel, because they stated that it was in a cast-iron case. The details given by Colonel Tannett-Walker with regard to fly-wheels were very interesting. It was possible, of course, to work out the details for a fly-wheel quite easily, but there was great difficulty in finding what other people had done with regard to their application, and it might therefore be useful if he gave some figures of a fly-wheel he had used lately and the work that it was doing. The fly-wheel weighed 30 tons and was running 500 revolutions a minute ; it was 12 feet in diameter, and the energy stored in it was 78½ million foot-pounds. It was used in connection with a coal-winder. If the electricity were cut off, the useful energy in the fly-wheel would give four winds, so that there was not much likelihood of the cage being stuck in the pit-shaft. The fly-wheel was on the same shaft with a motor and a generator, the load on the motor varying from 400 to 800 h.p. during the ordinary working hours, and the load on the generator—that is, the load given out by the fly-wheel and the motor combined—varied from nothing to 1,600 h.p.

With regard to the working conditions, the authors gave a voltage diagram, but did not say which machine it was taken off. They seemed to have three machines on the one shaft. One machine had special voltage regulation, controlled by a machine driven by a belt, and the authors did not say exactly whether that was a little exciter or whether it regulated a resistance, or what it did. Then on the end of the shaft there were two machines which were used for working the coal-hoists, and the coal-hoists test showed that the pressure used was 440 volts. The pressure on the capstan test was 240 and the pressure on the voltage diagram, Fig. 6 (page 13), was 440. That rather looked as if the pressure diagram was off the machine which was not regulated. He did not quite see how that was so, because there appeared to be no arrangement of balancing ; otherwise the capstans might be arranged in series across the outers, but he did not consider this probable. The authors, perhaps, might be good enough to make that point clear.

With regard to coal-tipping, some years ago he put up an electric tip ; lately he had to put up a coal-tip for tipping trucks in the electric power-station, and he installed a hydraulic tip because he

(Mr. William H. Patchell.)

found it was the cheapest and for general purposes the best. With regard to the angle of tipping, Colonel Tannett-Walker had made a great point of getting a " kick " at the end of the tip, and there was much to be said for that. In tipping a full truck of large coal it could be done at a comparatively low angle, probably 38°, but in tipping small coal, particularly if it had been washed, there was some difficulty in getting it out at 45° ; and if for any reason the tipping had been stopped and there was a quarter or half a truck to tip, it had to be practically raked out.

He would be obliged if the authors would give a little more information about the "Clyde" capstan, as it seemed to him it hardly compared with the ordinary capstan, appearing more like a vertical drum haulage-engine. Were the two speeds arranged electrically or mechanically? The authors termed it gearing, but then some people called electrical arrangements gearing.

With regard to the mains from the power-station to the various points of usage, the authors compared bare strip and insulated mains in favour of the bare strip. In the particular instance it might have come out cheaper, but the authors were in the happy position of the cuckoo who laid her eggs in somebody else's nest ; they had the culvert already made for them, and even then they appeared to have been not quite whole-hearted on the matter, because the photographs seemed to indicate some strip mains and some insulated mains. After all, the cost of the main did not depend on the cost of the copper or on the cost of the insulation entirely ; it depended in a great measure on the cost of laying the main.

On page 34 the authors made a claim which seemed to him to be a little bit too high. They said, " The plant at Rothesay Dock consists of an entirely new combination, arranged by the authors for the first time." Ignoring their particular figures of the combination of 450 and 936 h.p., he did not quite see where the entirely new combination came in. Applying a fly-wheel to an engine was not new, nor was it new to apply a fly-wheel to a motor. He knew of cases where a fly-wheel, a motor, and even a gas-engine, had been in running quite satisfactorily on the same shaft for many years.

Mr. Edward B. Ellington, Vice-President, congratulated the authors upon the boldness and originality of the work they had accomplished. He wished to have a little more explanation as to how it was they had to deal with so difficult a problem. There was a paragraph in the Paper in which the authors stated they did not expect to realize economy, but he could not conceive that the installations had been put in without the expectation of economy, for economy was the basis of really good practical engineering. He thought the authors had been too modest in their statement with regard to that matter. Any engineer who had to deal with a problem of the kind, as Colonel Tannett-Walker had said, would like to be in the position of obtaining the best possible efficiency with any system without regard to cost. The question of cost was really the bugbear of all engineers, and the Paper could hardly be properly discussed unless the authors gave some information—for there was none in the Paper—with regard to the capital cost of the installation.

He did not propose to deal, in the few remarks he had to make, in any detail with the majority of the mechanical problems involved. The Paper bristled with controversial points, but he would only say one or two words with regard to the conclusions to which the authors had arrived. The first conclusion was that electric and hydraulic systems were equally reliable. He thought that was a very bold assertion to make after a year or two's experience of new machinery. It was a well-known fact that through the genius of Lord Armstrong there had been some sixty years' experience of hydraulic plant, and there were many excellent plants working to-day that were put down some fifty or sixty years ago, which, eliminating the improvements that had been made since, were very nearly as effective as they were when put down. Until there was a very much more extensive experience of electric machines applied to the purposes for which hydraulic power had hitherto been used, it was quite impossible to state correctly as a fact that electric machinery was equally reliable.

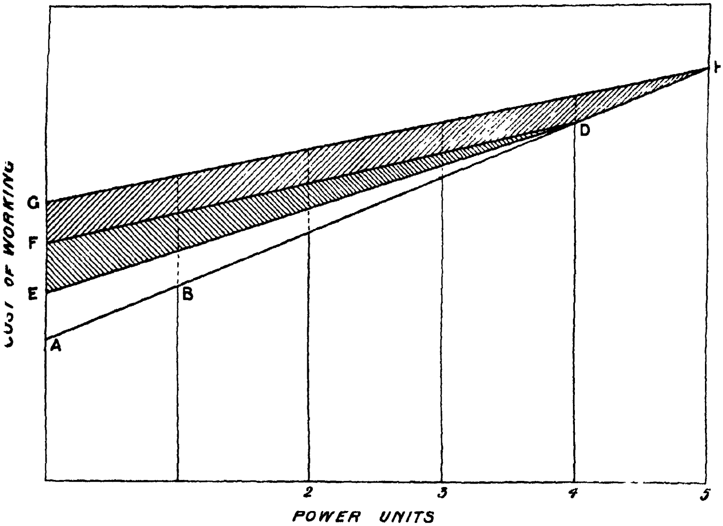
The second conclusion that the authors came to was that the cost of working with electric and hydraulic power was equal at full

(Mr. Edward B. Ellington.)

load, but under variable and low load conditions electric power was cheaper. He was in accord with the authors that on full load the generating plant of an electric and of a hydraulic station were equally economical; but he entirely differed from the authors as to the latter condition, that at variable and low load conditions electric power was cheaper. Further data were necessary to support this contention. He believed the facts to be exactly the reverse, and would illustrate by a diagram, Fig. 21, the principles which he thought governed the problem. The horizontal line represented quantity. Assuming that a certain amount of horse-power was put down at the central station, the quantity would be represented by a straight line, x 1, the verticals in the diagram, B 1, D 4, etc., representing cost of working at maximum load. The coal consumption and practically the cost of the boiler plant and the cost of running the station at full load, apart from capital charges, were admittedly

FIG. 21.

Diagram of Cost of Working. Comparison of Hydraulic and Electric Power.



equal for both systems of working. A central station could not be worked at any practical output, except at a certain minimum cost, as, for instance, given by the height A x. Doubling the power, it would be found that the line A B, representing costs, was continued practically straight. He had had some thirty years' experience of the work, and the information he was giving was based on that experience. Continuing from the point at which power had doubled to three and four times the amount, the line would continue on a straight line apart from small variations due to disturbing factors to a point, say, D. The point D thus represented cost of working at full load—equal for both systems. What happened when the plant was worked at low load? Costs did not then fall at the same rate as they rose when increasing the capacity of the plant. They did not fall back along the same line, D A, but along another line, D E, in the case of a station containing plant represented by x 4. When load had diminished to one-quarter the full power, the cost was represented by the length of the vertical through B and 1, up to the line D E, and so on. D E represented the only line along which it would be possible to go back for a hydraulic station of the size x 4. The working cost was reduced as the output was reduced, but the reduction was comparatively small.

A peculiarity with hydraulic plant was that the generating plant efficiency at low loads was greater with hydraulic pumps than with electric dynamos. Assuming with hydraulic power that D E was the line on which the cost of working at the different load-factors could be measured, it would be found that, in the case of electric power, the falling cost line would be represented by D F, which was always above D E. The area, D E F, was the difference in cost at different load-factors between working electrically and working hydraulically. That, however, was not the whole question, and it was quite understood by the authors of the Paper that, in dealing with the problem in a dock, it was impossible to arrive at an equality at the point of maximum load. If the dock were worked electrically, it would be found that additional plant must be provided which was represented by 4·5 on the figure, making for the horse-power needed at the electric central station x 5, which was larger than if

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the drive was hydraulic. Working at different load-factors with the plant x 5 would give falling costs along a line H G, and the difference in costs between the two systems would, therefore, be represented by the total area, E D H G, the difference at any point being the vertical distance apart of the lines, H G and E D, according to the load-factor. That was known to the authors, and they had inserted therefore a supposed equivalent of the accumulator in order to come down to equality, if possible, with the hydraulic horsepower which would have been required at the central station. It was in connection with that particular part of the problem that he was most anxious to have the fullest particulars that could be given, because on the question of the relative cost of hydraulic and electric power the Paper as it stood was useless, and not at all a satisfactory contribution to the controversy.

He accepted unreservedly the statement of results given in the Paper, but it contained a great deal more than mere results. There was a comparison of costs in pounds, shillings, and pence, the statement made being on the proportion of a penny per unit for the electric power used at the docks, and 9*d.* a thousand gallons for the equivalent quantity of hydraulic power used to do a given amount of work. From published data he believed that the statement of cost of the hydraulic power in this particular case was overrated. By examining the Paper it would be seen that the costs given were not statements of fact, but estimates of what the costs would be under certain conditions when these two comparative figures of 9*d.* and 1*d.* were used. Some of the facts were from Mr. Macaulay's Paper at Cardiff, but Mr. Macaulay stated that the cost of his hydraulic power at Newport was 2*d.* per thousand gallons. In the discussion on his Paper Mr. Macaulay stated that the 2*d.* per thousand did not include the capital charges; but the present authors stated that the penny a unit also did not include the capital charges, and in a later part of the Paper they said their present cost was 2*d.* a unit. Under the conditions in which hydraulic power had to be used in docks at low-load factors of something like 20 or 25 per cent., electric power was never produced at a penny a unit including capital charges. The [illegible] in Mr. Macaulay's Paper were not included, but these could hardly be expected to be more than double the cost, and there was every reason to suppose that the effect of capital charges in the case of a dock would increase the electric-power cost to a larger extent than the hydraulic. Therefore the statement of comparative cost of 18*s.* 11*d.* and 10*s.* 11*d.* per thousand tons, as given in Table 4 (page 20), could only be obtained on the assumption that the electrical cost had been halved and the hydraulic cost doubled.

He also wished to ask the authors what they meant by a statement on page 32, as he did not understand it. They said: "Whereas the supply of electricity to any given quantity of work is a direct measure of the work done, the supply of water in the case of hydraulics is always more than the quantity required, and therefore some of it is wasted; this waste may vary from 5 to 50 per cent." Of course, anything might vary, but the question was: What was that waste? He had always taken it that hydraulic machines, all things being in good order, were the most perfect meters of power, and the waste in hydraulic plants was, or ought to be, extremely small. In London streets there were 170 miles of hydraulic-power pipes, the pressure in most of them being from 750 to 800 lb. per square inch, the power being supplied from the central stations at about 800 lb. per square inch. The quantity of water which was registered in the meters had for years past exceeded 95 per cent. of the quantity pumped into the mains. It was well known that meters on the whole registered less than the quantity flowing through them, and the percentage registered showed that the waste must be extremely small.

He had great sympathy with the opinions that had been expressed that no engineer—and he thought certainly no mechanical engineer—ought to wish himself to be dubbed a particular kind of engineer in the sense that he was not open to conviction, and was not prepared to use all the powers of nature which came under engineering control. If electric power had been intended to do everything, there would have been no water-power to work with. It was curious to think that water-power was the power of the future and that engineers would be dependent on water-power to create electric current in the cheapest way. That was an undoubted fact, and all the different systems were simply means of transmitting energy either from the power of water or the power of combustion of coal to the place at which the energy was wanted, and there converting it for use. It often happened that certain different conversions were better done electrically while others were better done hydraulically, and others, perhaps, better done by compressed air. There was no royal road, and he agreed with the authors that every problem must be dealt with on its own merits.

Mr. CLARENCE O. RIDLEY (Messrs. Armstrong, Whitworth and Co.) said that, speaking as a manufacturer, he most heartily endorsed what Colonel Tannett-Walker had said, although, perhaps, the Colonel had said it a little more forcibly than he himself was capable of doing. Particularly did he agree with him on that craving for cheapness now so prevalent. The electrical engineer apparently had unlimited cash at his disposal with which to make experiments and obtain credit, but very seldom was money spent nowadays on what might be called "commercial hydraulics." Manufacturers could not afford it, not being paid sufficient for the goods they supplied in competition. They very seldom had the chance of spending a great deal of money in showing what could be done if purchasers would pay the price. It might be, perhaps, rather a far cry from coal-hoists to gun machinery, but certain comparisons might be made. In gun-training machinery hydraulic machines had been used for many years, but there came a time when the electrical engineer said he could do all the work if he was only given the chance. The chance was given him, and he received a specification for a gun-turret weighing about 509 tons, which made him think that perhaps he had got something more than he could cope with. But still he was quite satisfied with it and proceeded with the work. There were two main conditions that had to be fulfilled. The first was quick speed, the turret having to complete one revolution in a minute and a half. That the electrical engineer performed quite easily. He then proceeded to the slow speed, a speed by which the turret had to continue to rotate and complete a revolution in nine hours, moving continuously. That gave the electrical engineer food for thought, but he was not in the least downhearted. He introduced into his train a gear, a device known as the "Janny-Williams" device, and believed he had accomplished his object, but forgot that the device was a hydraülic motor.

It was rather difficult to pick out subjects not already dealt with from the Paper, which bristled with points inviting criticism, but he noticed there were two "bogies" brought forward, which appeared in every Paper comparing hydraulic with electric machinery, namely, frost and moving ground; these were spoken of as being two conditions influencing a would-be purchaser against hydraulic machinery. Too much was made of both those points. To begin with, in such a dock there was always a shelf behind the wall which was the proper place for the pipe, where it was covered up and where neither frost nor sinking ground could affect it. Speaking of frost as affecting machinery, in how many years during the last twenty years had there been winters with sufficient frost to do any material damage? In the last twenty years he thought there had been three. From the point of view of replace orders for burst cylinders, he thought the material damage had practically amounted to nothing. If proper precautions were taken against frost there need be no trouble, and he presumed that the electrical engineer had to take proper precautions against damp, which was present nearly everywhere and practically always. If damp was not a matter of serious consideration to the electrical engineer, why did the authors put their controlling gear in a little house above the ground away from the motor in the pier-head capstans? Also, why did a great many specifications nowadays insist on the contractor playing the hose on the capstan-casing after it had been finished, to show that no spot of water could get inside?

With regard to moving ground, there was no necessity to be frightened of it even when cast-iron pipes were used. If the proper proportion of distance-pieces was employed between the flanges, there should be no difficulty. He could show plenty of cast-iron pipes laid in mud and unsupported, none of which had ever failed. If, however, one was afraid of cast-iron pipes, there was the Mannesmann steel-tube which was now being employed very much

(Mr. Clarence O. Ridley.)

more extensively than it ever was before. At Immingham the whole of the pipes—pressure and return-water—were being made in solid-drawn steel; and at Methil also, where there was sinking ground, the pits being within very few fathoms of the surface, there was to be nothing but steel tubes used. It was practically impossible to break them.

With regard to the question of control, a great point seemed to be made of the single lever. After all, a man had two hands, and in a coal-hoist two levers were none too many for him to deal with; but still if a single-lever gear was desired in hydraulic machinery it could be had. It had been used for many years on board ship, and had only been given up because it was recognized that one man in dealing with a gun could not think vertically and horizontally at exactly the same moment.

He had intended to say something about the capstan, and referred to the diagram on the wall of a hydraulic turnover-capstan. There was nothing new in a wire-rope reel capstan, and he thought it was impossible to improve upon a capstan of the type such as that shown in the cartoon. It had the advantage, moreover, which the Clyde capstan had not, that it would turn over, and thus one could get to the under side, and that was a considerable advantage in a wagon-hauling capstan at a dock. Mr. Ellington had pointed out that hydraulic machinery lasted a good long time, and his own experience was that it lasted much too long. He had been rather amused recently to receive a request from the engineer of a big railway company to send them a drawing of a certain crane, number three on his Firm's list, and one which was quite out of date. The document was sent to the engineer, and a few days afterwards he was asked what he wanted it for, and he then said that he was going to take down the crane and re-erect it in another place. That was no good to manufacturers.

Discussion on Friday, 17*th February* 1911.

Mr. WALTER PITT, Member of Council, in opening the resumed discussion, said he had not a long contribution to make to the discussion and he confessed he would rather have seen it run on somewhat different lines. The members had been girding at one another by saying, "My crane will lift faster than your crane." Surely, however, the question of speed had nothing to do with the question of motive power. He presumed that a competent mechanical engineer would make a coal-hoist, a crane, or a capstan that would work at any speed, provided he obtained enough power. He thought the members had to look elsewhere for the reasons why electric drive was rapidly gaining ground in dock installations and in other places. He thought the secret of its success lay in the generating station; largely in the transmission; and, naturally of course, in the machine itself. He held very strongly that an electric central station was a more useful general servant than a hydraulic station. More things could be done with it. From the electric station the docks could be lighted and all the plant could be driven, and it was the convenience of electric transmission that had made it the force it had become. The power could be taken anywhere. It could be taken into all sorts of corners; it could be taken across the water; it could be taken through the air, and all that work could be done at an economical rate.

Then, with regard to the machines themselves, where the power was developed, there could be no doubt that they were economical machines. A dock engineer, having settled whether he would have an electric station or a hydraulic station, had several problems to solve. If he had settled on an electric station, he then had to ascertain how he could work electrically all the machines which had up to the present been the special preserve of the hydraulic men, and he held it was the particular merit of the Paper that the authors showed that one of the machines which he believed had been considered up to the present to be essentially

(Mr. Walter Pitt.)

a hydraulic machine, namely, the coal-hoist, could be worked successfully and economically electrically. Such work was gradually being taken away from the hydraulic men, and the electrical men were naturally gathering it in.

With regard to the other part of the plant, the only part of it with which he had personal considerable acquaintance was the cranes and the capstans. Speaking first of all of the capstans, all the claims that the authors had made for the "Clyde" capstans, namely, the electrically-driven free-head capstans, he had found, *in Clyde capstans his firm had made for other installations*, to be *fully substantiated. One of the points where electric drive showed up was that it was possible to see what was being done. Meters could conveniently be put on the capstans, and it was a perfect revelation to learn from the diagrams how much the rope was* fretted on a warping-head, and how much work was lost simply in rope scrub; there was no doubt that the saving of the capstan-rope, where it was fastened rigidly, was immense.

With regard to electric cranes, he noticed that their hydraulic friends left out the crowning glory of the hydraulic crane, namely, the great ease, as he knew from experience, with which it could be converted into an electric crane. On the cylinders being taken out, an admirable space was obtained for the collector for the leads, and on the back of the crane there was a place, just as if it was made for it, on to which the electric motors could be bolted.

Mr. Roger T. Smith said that the authors, in considering the shipment of coal, had only contrasted the tipping of wagons after hoisting either by hydraulic or by electric means. He thought that in any modern dock-equipment, involving the shipment of coal, consideration should be given to the plan of tipping into a hopper and delivering from that hopper on to a conveyor-belt, the belt being inclined and ending in a shoot. To that shoot could be attached any of the anti-coal breaking apparatus so essential in the shipment of some kinds of coal. Where electricity was used for very variable loads the Rothesay Dock constant-torque engine, overloaded 100 per cent., was a convenient and admirable method of meeting such sudden overloads as were required for hoisting, but he would like to call attention to the fact that in Tables 1 and 2 (page 18) it would appear as if the fly-wheel effect had got to last for something like 40 seconds. He wished to ask the authors how long the fly-wheel effect was supposed to last, because the overload of 100 per cent. which it provided appeared to be necessary both for hoisting and for tipping, and it was not quite clear from the diagrams whether there was a pause between the two. Compared with the hydraulic accumulator, the first cost of a heavy fly-wheel plant was expensive, but compared with a battery and a battery-booster it was cheap. It was important to note, however, that in order to do the hoisting at the Rothesay Dock it was necessary to provide engine-power up to 250 h.p. overloaded 100 per cent. so that about 500 tons of coal might be delivered per hour.

In the North of England coal-conveyors were largely used. In the Victoria Dock at Hull on the North Eastern Railway two belt-conveyors 42 inches wide could, and did, deliver 750 tons per hour to a height of about 40 feet, and regularly delivered 600 tons an hour. Each of these belts was driven by a 100 h.p. gas-engine. Also at Hull the Hull and Barnsley Railway had erected at their Alexandra Dock two conveyors, each having a capacity of 500 tons per hour, and they had ordered another. One of these conveyors has been at work for several weeks. In the dock which the Hull and Barnsley Railway were making conjointly with the North Eastern Railway three conveyors, each to deliver about 600 tons an hour, had been specified, and were to be driven by 60 h.p. motors. At Hartlepool on the staithe between the Old Harbour and the Victoria Dock there were eight belt-conveyors, each capable of dealing with 600 tons per hour, and he had himself watched them deliver 750 tons an hour. Each of these conveyors was driven by a 25-h.p. motor. On the Tyne at the Albert-Edward Dock the Tyne Commissioners used several belt-conveyors, while the North Eastern Railway had five belt-conveyors at Tyne Dock which were the first used in this country for shipping coal. Belt-conveyors were also in use at Blyth, and at Whitehaven a belt-

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conveyor for delivering 500 to 600 tons an hour had just been erected, and was about to be brought into use, fitted with the latest form of anti-breakage box, with a spiral staircase for the coal to slide down, and a revolving spout at the bottom for trimming.

He thought the conveyor possessed the following advantages over the hoist for the shipment of coal: (1) that for the same capacity the initial cost of the conveyor was from a quarter to half the initial cost of the hoist; (2) that the load factor at which the machine worked was 80 to 90 per cent., because the maximum load was the same as the average load; (3) that there was a greatly reduced weight on the tower supporting the free end of the conveyor (which rose and fell) as compared with the weight of the hoist, thus lessening the cost of foundations or the cost of the jetty, if a jetty was necessary; (4) there was a possible saving in land for sidings, because instead of all the sidings having to come end-on as was necessary for the hoist, they were much better arranged parallel with the quay; and (5) there was an enormous reduction in the maximum demand on the power-supply. The success of coal-conveying depended on the life of the belt. At the present time cotton belts could be obtained in the North of England guaranteed to deliver one million tons of coal. If a belt cost £250 to renew, this sum divided by a million was not a very formidable addition to the cost of shipping per ton. The great advantage of the belt-conveyor was the reduction in the maximum load, amounting to something like 80 per cent.

He could not, unfortunately, give figures of the working costs of any of the coal-conveyors in the North, but he had figures relating to a small clay-conveyor he had designed which had been working for the last eighteen months at Fowey, a port in Cornwall where the Great Western Railway shipped china clay. The conveyor which was hinged had a lift varying from 25 to 48 feet. It had shipped 150,000 tons of clay during the past year, the energy measured at the generating station giving 10½ tons of clay lifted per kw.-hour, inclusive of all idle running. That compared with 7 tons per kw.-hour for the Rothesay Dock tips given in the Paper (page 22). In the amount of 10½ tons per kw.-hour the cost of tipping was not included, because it had seemed preferable to tip by gravity, power only being used to lift one end of the empty wagon. This gain, possible with clay, might not be possible with coal where breakage was important. For delivering by the belt 200 tons of clay per hour to a height of 40 feet, the horse-power used was only 24, and the horse-power for moving the empty belt at the same speed was 5½. That gave an efficiency of the belt itself of 77 per cent., while at Hull, dealing with much larger quantities, the efficiency of the belt was as high as 90 per cent. A belt-conveyor to deliver 500 tons an hour raised 46 feet required about 60 h.p. On Table 4 (page 20), as already stated, it appeared that for 500 tons an hour raised 46 feet and tipped by the electric hoist 250 h.p. overloaded 100 per cent. was necessary. That is to say, that as between belt and hoist, taking the capacity of the generating plant necessary to meet the same load under the circumstances, the belt required only two-sevenths of the generating plant required by the hoist supposing this plant was overloaded 100 per cent., or only one-seventh of the maximum demand, that is to say of the generating plant, provided this was not overloaded by any such arrangement as had been described. If the power was bought on a maximum demand basis, or if it was generated, which from the point of view of cost came to the same thing, only one-seventh of the maximum demand required by the hoist was required by the belt, and this was a matter of such importance that he ventured to predict that in ten years' time no more hoists, either hydraulic or electric, would be put up where conditions made conveying convenient. There was no reason why a belt-conveyor should not be driven by a hydraulic engine, in fact it was a very suitable load because it was full load all the time. There was to be seen at the Albert Dock, Hull, at the present time a belt-conveyor worked by a hydraulic engine. The Newport hydraulic tips, described by Mr. Macaulay and referred to in the Paper, appeared to require about the same pump horse-power in the pumping station to meet their maximum demand as the Rothesay Dock hoists, namely 250 h.p. overloaded in this case by the hydraulic accumulator. Comparing the energy required to deliver 500 tons per hour to a

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height of 46 feet and converting water into kilowatt units the comparison would appear to be (*see* Table 4, p. 20)—

Newport hydraulic hoist	0·164	kw.-h. per ton raised 46 feet.
Rothesay Dock electric hoist	0·131	,, ,, ,, ,,
Fowey electric conveyor (exclusive of tipping).	0·095	,, ,, ,, ,,

He wished to supplement what Mr. Pitt had said with regard to the Clyde capstan. After seeing Clyde capstans at work at the Rothesay Dock, the Great Western Railway Company ordered twenty-eight of them because they were convinced that what had been claimed for those capstans was substantiated. Their great advantage was, first, that the maximum demand on the generating station to haul the same load as compared with that of the slipping-rope capstan was decreased 50 per cent. and the energy by 30 per cent.; but, what was of greater importance, the cost of rope renewals was reduced by 80 per cent. to 90 per cent. A slipping-rope capstan was first of all a rope-brake, from 50 to 80 per cent. of its power being simply wasted in wearing out the bollard and the rope, only the remainder of the power being available for hauling. Railway experience in very busy yards would put the annual cost of ropes with the slipping-rope capstan not at the figure given in the Paper as £15 a year, but at the higher figure of £20 a year. Fourteen Clyde capstans were employed at the railway yard at the harbour of Fowey, where the conveyor already referred to was installed. Those fourteen capstans hauled during the past year more than one million gross tons, or an average of 75,000 tons per capstan. The cost of ropes had been £2 10*s*. per capstan per annum, a result obtained with capstans handled by people who have never seen a capstan before, and a great many ropes were run over. With better supervision, the figure would be less than the one he had given. If, on the other hand, slipping-rope capstans had been used, the £2 10*s*. would have been somewhere in the neighbourhood of £20. Each of these capstans had taken on the average 1,000 kw.-h. during the year. Taking that at 1*d*. a unit—which was not the price at Fowey, but the price used in the Paper—the cost was £4 3*s.* per annum. It would be seen, therefore, that the cost of ropes in a slipping-rope capstan, supposing both types took the same energy, was nearly five times the cost of electricity at 1*d.* per kw.-h., and if 80 or 90 per cent. of the cost of rope renewals could be saved, the advantage was very substantial. He therefore thought the authors were perfectly correct in refusing Colonel Tannett-Walker's offer of a hydraulic capstan, provided it was of the slipping-rope type, even if the capstan had been given away. If the annual saving of something like £18 a year in ropes was capitalized at 4 per cent., two Clyde capstans could be bought with the capitalized savings, and it would almost appear as if the purchase of Clyde capstans was a way of making money.

Mr. C. S. MEIK said that advocates on both sides of the case had joined in the discussion on the Paper, and it seemed to him the question resolved itself more or less into the question of hydraulic versus electric power. He was not present at the Meeting as an advocate of either system; he was present as an inquirer after facts. It had frequently been his lot to advise clients such as Companies and Corporations as to what they should erect in the way of machinery, more particularly for handling coal. He recalled an instance which occurred six or seven years ago where he was asked to advise a Company on the Thames as to what machinery they should erect for unloading coal from steamers. On looking into the question, he found it was a case of hydraulic versus electric power, and the question he had to decide was, which was the better of the two. He found it was very difficult to get any reliable costs, more particularly working and maintenance costs, of electrical machinery. When he noticed that a Paper was to be read before the Institution dealing with the question, he thought he would eventually be able to obtain reliable information because the Paper dealt with a large dock installation in Scotland.

In the particular case to which he was referring, three points had to be considered: (1) the cost of the plant; (2) the cost of

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producing the power; (3) the cost of working and maintaining the cranes and other machinery. Dealing with the first point, the cost of the plant, he came to the conclusion at the time that the cost of first rate plant was practically the same for both hydraulic and electric power, and he was glad to find that was borne out by the statement made by the authors (page 34), where they admitted that the cost was the same in either case. So that the first point to which he referred might be dismissed. Coming to the second point, the cost of producing the power, figures referring to hydraulic power were available, if the engineer went to the proper place to get them, and electrical statistics were also available; they could be obtained from the electrical papers and other sources. After full consideration, he found there was not much to choose between hydraulic and electric machinery, so far as the cost of producing the power was concerned. As the installation was a small one, he told his clients there was very little to choose between the two systems, but if they could buy electric power at 1½*d.* a unit, they should do so by all means and put up electrical machinery. Unfortunately, they could not purchase electric current, as there was no generating station near the site—West Ham, where power could be obtained at a low rate, being too far off for practical purposes. He therefore told his clients that under the circumstances, he thought they would be safer to use hydraulic power, and they followed his advice in that respect.

Still dealing with the point of the cost of producing the power, he had examined the Paper in the hope of finding reliable information upon which he could work in the future. Table 4 (page 20) gave certain calculations, figures and costs, for electric and hydraulic power, the hydraulic being taken at 9*d.* per 1,000 gallons, and the electricity at 1*d.* per unit. Further on (page 22) under "Cost of Working" the authors gave the cost of electric current at 1*d.* per unit, and of hydraulic power at 9*d.* per 1,000 gallons. When he read that paragraph in the Paper he concluded that the electric power at the Rothesay Dock cost 1*d.* a unit and that the hydraulic power at the Clyde Docks cost 9*d.* per 1,000 gallons. Further on in the Paper, however, the working costs were given (page 31). He supposed "Working Costs" meant something different from "Cost of Working," because the figures were different. He there found that: "The actual works-costs are, on an average, with a consumption of approximately 560,000 units per annum, approximately 0·89*d.* per unit. Taken over periods during which the dock was busy, and consequently more units being generated, these costs were in the neighbourhood of 0·6*d.* per unit. The capital charges at present increase the above figure of 0·89*d.* to approximately 2*d.* per unit, but, of course, in the incompleted state of the dock these capital charges are out of all proportion." He presumed from the above figures that the actual costs at present were 2*d.* a unit. The authors were very optimistic, and no doubt thought they would attain the figure they had previously mentioned, and he (Mr. Meik) hoped so too; but the fact remained that the costs at Glasgow at present were 2*d.* a unit, and in making any calculations that fact had to be recognized. So far as the hydraulic power was concerned no actual costs were given, only estimates; but he presumed that some figures were available with regard to the working of the docks on the Clyde, and he failed to see why the authors had not given them in the Paper. In that connection it might be useful to remark that in the discussion on a Paper read at the Engineering Conference at the Institution of Civil Engineers in 1903 by Mr. Walter Pitt, some figures were given by Mr. Baxter of the cost of power at Glasgow in that year. The electric power then cost 2·56*d.* per unit, and the hydraulic power apparently cost 17·67*d.* per 1,000 gallons, which of course was a most excessive price. Compared with those figures he wished to give the following Table which he had obtained of the hydraulic power costs at the Swansea Docks for the years 1906–7–8. His firm advised the Swansea Harbour Trustees about four or five years ago in conjunction with the Harbour Trust Engineer, Mr. Schenk, as to the machinery that should be installed there, and Table 6 (page 64) was based on the figures supplied to him by that gentleman.

Coming to the third point he had mentioned, the cost of working and maintaining the cranes and other machinery, in 1903 he could

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TABLE 6.

Year.	Quantity pumped.	Pressure.	Working costs per 1,000 gal.	Capital charges per 1,000 gal.	Total excluding administration per 1,000 gal.	Administration allowance 10 per cent. per 1,000 gal.	Total costs per 1,000 gal.
	Gallons.	Lb. per square inch.	*d.*	*d.*	*d.*	*d.*	*d.*
1906	200,000,000	750	5·39	2·26	7·65	0·765	8·41
1907	215,000,000	750	5·35	2·03	7·38	0·738	8·12
1908	227,000,000	750	5·42	1·96	7·38	0·738	8·12
Quoted. Average of 3 years.	214,000,000	750	5·39	2·08	7·47	0·750	8·22
Quoted. Equivalent price per B.T. unit.	—	—	0·83	0·32	1·15	0·115	1·27

Notes.—1,000 gallons of high-pressure water at 750 lb. pressure is equal to 6·5 B.T. units.
Cost of coal (small) at Swansea, 8*s.* to 9*s.* per ton.

not obtain any reliable statistics on the point, and the conclusion he then came to was that as regards the working, the driver's wages, and stores, the cost would be practically the same in the two systems, while so far as the cost of the power consumed by the different machines was concerned there was also very little on one side or the other. The cranes were for lifting coal and usually had a full load, and consequently there could not be much difference in the actual cost of the power consumed whether hydraulic or electric. Possibly the electric might have a little advantage, when the cranes were not lifting their full loads, but as there was only a small consumption of power there was very little in it. While dealing with the question of power consumed, he had compared certain figures given in Table 4 (page 20), using the power costs at the Rothesay Dock and those given on the previous page for Swansea Docks. According to the Table, the energy consumed per ton of coal at Newport was 25·22 gallons of high-pressure water. He worked that out at the Swansea price of 8·22*d.* per 1,000 gallons and he found that it cost 0·210*d.* per ton of coal shipped. Taking the electrical energy at the figure given in the Table of 0·131 unit per ton of coal, and working it out at the actual price of 2*d.* per unit instead of the price the authors expected to obtain, he found it came to 0·262*d.* per ton of coal. That showed a balance in favour of the hydraulic machinery. He did not mean to say that it was not possible for electric power to perform the work at less cost, possibly it might do so, but he would like actual costs to show it could be done, and he very much desired a speaker on the electrical side to give some really reliable figures, and not estimates.

Coming to the question of maintenance, which formed part of the third point he had mentioned, there were no figures available in 1903 with regard to electric cranes, nor had he been able to get any reliable figures since, although he had tried in many quarters. It appeared to him that rams, sheaves, and ropes had to be considered in hydraulic cranes, and motors, gearing, and ropes in electric cranes. The first was a machine with slow-motion and the second was with quick-motion machinery, and he came to the conclusion that the quicker-motion machine would be the more

(Mr. C. S. Meik.)

expensive to maintain. Possibly some engineers might say he was wrong in coming to that conclusion, but that was the result he had arrived at, and he saw no reason to alter his opinion now. His clients adopted his advice and put up hydraulic machinery, and although electrical machinery might hereafter improve upon the figures which had been given, up to the present the hydraulic system had justified its existence in the particular instance to which he was referring.

He thought the authors might have given more particulars in the Paper with regard to the maintenance question. They said (page 17), under the head of *Capacity*: "Comparing these with the results tabulated in Table 2 (page 18) which were obtained in February, 1909, after two years' working, it will be seen that the time required for coaling through the cycle of operations is considerably shorter." So that the hoists referred to had been working for two years, and there must be some records in existence of what they cost to maintain. Again on page 23 under the heading of *Maintenance*, the authors said: "The result of two years' working shows that the cost of upkeep has not exceeded, and is not likely to exceed, that required for the upkeep of coal-hoist plant operated by hydraulics or steam." Would the authors kindly give the actual figures? Summarizing what he had said in the particular instance to which he had referred, the cost of the plant in the two systems was practically the same; the cost of the power with full loads was also practically the same, although with variable loads there was no doubt the electrical machinery had an advantage. The hydraulic machinery he thought had the advantage so far as maintenance was concerned; and in view of what he had said, he did not see that he could alter his opinion until some definite statistics were available to show him he was wrong. Before concluding, he wished to say a word in favour of one part of the Paper, and that was the information given with regard to the electric capstan. He had seen the capstan before, and believed it was a very good machine. There was no doubt that the old hydraulic capstan in particular was one of the most wasteful machines that could be erected.

Mr. C. J. HOBBS said the authors drew attention in their Paper to the very excellent Papers which were read at the Summer Meeting of 1906, and he remembered one of the speakers saying that, as an electrical engineer, he felt he had fallen into a stronghold of hydraulic engineers. On that occasion he (Mr. Hobbs) considered the hydraulic case rather proved itself. He thought, however, at the time it would not be very long before something else would be heard in reply, and therefore he welcomed the present Paper very much indeed. He did not think the authors at present had made out a very strong case in favour of electricity as against hydraulics for appliances of the nature described. There was one point on which those who advocated electricity for the purpose seemed greatly to rely, namely, that when they came to meet the load for which the plant was designed, they found, instead of having the full load, only a small proportion of it. They then turned round and drew attention to the extreme flexibility of their power as compared with hydraulics as far as the consumption of water was concerned. That was very clearly seen in the case of the electric hoists at the Rothesay Dock. Those hoists were designed for a gross load of 32 tons, dealing with wagons of 20 tons. As a matter of fact the Paper showed that, instead of dealing with 32 tons, or 20 tons net, they dealt with loads of 8½ tons, or only 42·5 per cent. of the specified load. Results were given on page 20 which were compared with results obtained in practice with one of the coal-hoists at Newport. He did not think it had ever been suggested for one moment that that coal-hoist was a modern one. He believed it was reconstructed shortly before 1906, so that it could not be said to be an altogether modern coal-hoist, and possibly—he did not know for certain—it was not as quick as an ordinary coal-hoist built at the present time.

The authors stated (page 22) that if their wagons had been loaded up as much as the wagons at Newport, they would have lifted 477 tons as against 444 tons at Newport. He desired to suggest, as a practical point in the handling of coal, whether the lifting of the wagons and the manipulation of the coal did not vary

(Mr. C. J. Hobbs.)

somewhat directly with the quantity of coal in each wagon, and he did not think therefore there was very much in the authors' point of their obtaining *43* cycles as against *40* cycles at Newport. That, however, was not very important; as Mr. Pitt had said, it was no good arguing about speed.

He wished to draw attention to Table 4 (page 20), in which the results at Newport were tabulated. There he found the cost of water per 1,000 gallons was 9*d.*, but originally it was given as 2*d.*

TABLE 7.

—	Gross Weight.	Net Weight.	Energy per cycle.	Energy per hour.	Height of lift.	Energy per ton of coal.	Equivalent Energy in B.T.U. for 1,000 gal. at 700 lb.	Cost per 1,000 tons at 1*d.* per unit.
	Tons.	Tons.	Gal.	Gal.	Ft.	Gal.		*s.* *d.*
Garston	1,200	748	318·1	12,724	46	17·00	0·103	8 7
Hydraulic Engineering Co.	1,200	748	278·3	11,132	46	14·87	0·09	7 6

This seemed to be an abnormal rise in the price of material. He did not intend to raise any argument as to the price of generating power, because the question was very ably dealt with at the previous Meeting. He had, however, had Table 7 (above) prepared, in which the results were based on water-consumptions taken from the rams of some coal-hoists which were made by his Company for the London and North Western Railway at Garston. For the sake of argument, he had assumed that the net load of coal lifted bore the same proportion to the gross load as in the case mentioned in the Paper; he had also assumed the height of the lift as 46 feet. He gave the quantity of water which was consumed, and converting it to Board of Trade units, as suggested by Mr. Aspinall at the previous Meeting, and as adopted by Mr. Meik in the figures he had just given, the equivalent energy in B.T.U. (assuming 1,000 gallons at 700 lb. was equivalent to 6·06 units) worked out to 0·103 unit per ton of coal lifted as against 0·131 unit, and 8*s.* 7*d.* per 1,000 tons shipped as against 10*s.* 11*d.* in Table 4.

These coal-hoists were designed to take wagons from an elevated roadway, and either raise or lower them to the required tipping level, and afterwards deliver the empty truck on to the elevated roadway, the rams being arranged accordingly. For the sake therefore of further comparison he had prepared another column, in which it was assumed that the coal-hoist was designed to meet the exact requirements at Rothesay Dock, and the rams arranged for raising loaded wagons from the ground, lift them to the required height for tipping, lower the empty wagon on to the intermediate railway, and descend with the cradle empty to the quay level. It was a very simple matter to arrange the rams for such a purpose. The consumption came out at the figures shown, and the equivalent energy in Board of Trade units was also given. He confessed that this was a somewhat hypothetical argument, but he thought it was a very fair comparison, taking into consideration the arguments with regard to 9*d.* per 1,000 gallons put forward by the authors. The chief reason he had drawn attention to the question was that he did not think it was at all fair that the statement made on page 32 should go forth uncontradicted that in future it was going to cost 8*s.* more, per 1,000 tons, to ship coal by hydraulic power than by electric power, and that was why he referred to the matter so strongly.

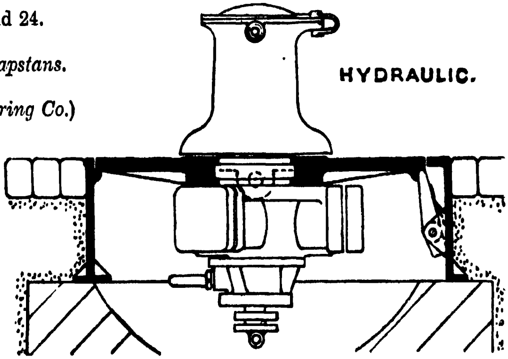
He would not say very much about the practical points of the coal-hoists, because the subject was very ably dealt with at the previous Meeting by Colonel Tannett-Walker, but he would like to say that, as far as the one lever was concerned, he thought it was a very great drawback that the operator should not be allowed to perform two operations at the same time, that is, the lifting and the tipping, which he presumed would be impossible on the Rothesay Dock coal-hoist.

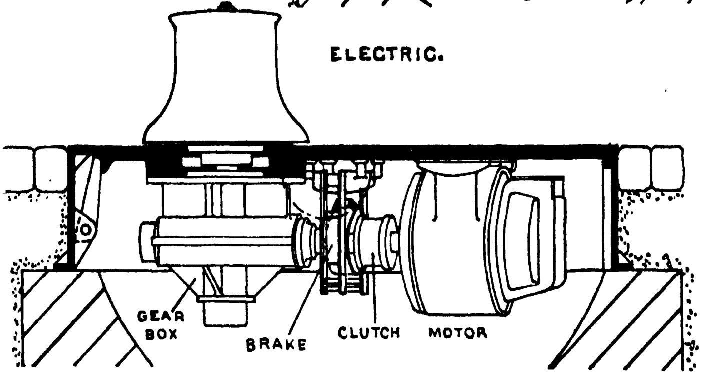
(Mr. C. J. Hobbs.)

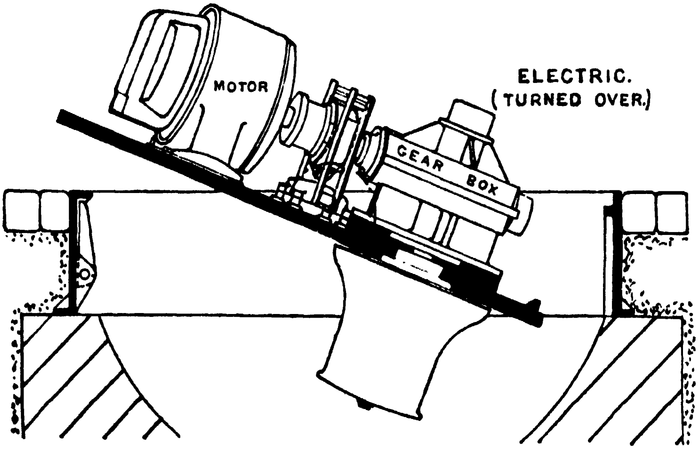
Figs. 22, 23, and 24.

1-*Ton Turnover Capstans.*

(*Hydraulic Engineering Co.*)







With regard to the capstans, he confessed he did not quite understand exactly what the authors meant by a loose head, and he hoped they would give a little further information on that point.

Fig. 22 showed a diagram of a hydraulic capstan with a head which could be fixed or made loose as required, fitted with a simple hand-clutch at the top of the head. It was a type of capstan which had been adopted very largely by the Alexandra (Newport) Docks, and he believed it worked quite satisfactorily. Mr. Ridley informed him at the previous Meeting that a number of capstans with the same type of head had been installed at Grangemouth. He did not intend to say anything about the economy of a hydraulic capstan, nor did he know that any engineer had ever spoken of a hydraulic capstan as a remarkably economical machine, because it was not. It could, however, be exposed to all weathers, moisture, and to the very roughest work; the electric capstan, however, seemed to have more self-respect. If it was over-abused it had a tendency to spit fire, and if the fuses failed to act, it might eventually burst into flame. However to meet, if necessary, any drawbacks of this nature, Figs. 23 and 24 showed an electric capstan made by the Hydraulic Engineering Company, Chester, which to a certain extent he considered had some marked advantage over that shown by the authors. The same turnover system had been adopted as in the case of the hydraulic capstan, and the principle was followed on exactly the same lines. The diagram showed the position of the motor, the clutch, the brake and the gearing, but the switch-gear was arranged in a separate air-tight case by itself outside, thus avoiding the necessity of it being placed in the damp portion of the foundations below.

In conclusion, it had often occurred to him, supposing at the present time all appliances were worked by electricity, and there were no hydraulic appliances of any kind whatever, and somebody was suddenly to discover a simple-acting lift, or a hydraulic jigger, what a very great sensation would be created. He thought also that electrical engineers would have a very difficult position to defend, on account of the extreme simplicity and safety of

(Mr. C. J. Hobbs.)
hydraulic machinery; he considered that hydraulics had to a certain extent suffered on this very account, and economy had in many instances been sacrificed. He therefore asked that any complete hydraulic scheme should be given the same consideration as an electric scheme, and every opportunity of proving its case in economy of generation and production; if that were done, he ventured to think that not only would hydraulic machinery prove itself cheaper in first cost and more economical in maintenance, but quite up to and even superior to its sister power—electricity.

Mr. E. GODFREY BREWER said the authors had read a most interesting Paper, and a number of speeches had been made by members professionally interested in either one side or other of the question, namely, hydraulics or electrics. Personally he held no brief for either system, but desired to make a few remarks on the loading of coals and minerals into ships by means of the gravity system, which if used in conjunction with high-capacity wagons, could be done at not more than one-twentieth of the cost per ton now expended on hydraulic or electric energy. The system was not a new one; it was in use almost universally in the United States, and to a very large extent in Spain. The speakers who had taken part in the discussion had praised their respective systems, one by saying that he had a large reserve power in his fly-wheel, and another that he had a reserve of 40,000 h.p. in his hydraulic accumulator, but with the gravity system if the loading stage were fitted with a large storage hopper it was possible to have 8,000 to 10,000 tons of coal or iron ore ready to be discharged into vessels at a moment's notice. In one plant with which he was acquainted in Southern Spain, to load in twenty-four hours 8,000 tons from one double-sided tip was considered quite an ordinary day's work, and this was done by twelve men without the expenditure of any hydraulic or electric power. His opinion was that if neither hydraulic nor electric power had been invented we would be loading coal in England at far less cost than we were now doing.

The position of the coal-hoist in England was rather a peculiar one. He remembered some years ago assisting in a campaign for the introduction of high-capacity drop-bottom wagons on to English railways. The railway companies were first approached, but they stated that it was impossible for them to adopt this class of vehicle on their railways, because they would not go on to the coal-tips. They, therefore, went to the dock companies, and told them what the railway companies said, but were met with the reply that they would be only too glad to adapt their wharves to handle high-capacity wagons if the railway companies would supply them; but the railway companies informed them that they had so much capital sunk in small wagons that it was impossible for them to adopt large ones. The general position of large coal ports in England at the present time was that the coal mines were situated in the high lands at the back of the ports, and the railway companies took a great deal of trouble to bring the coal down to the dock level. When the coal had been brought down to the dock level, it was then put on a coal-hoist and lifted up again. Surely the proper thing to do when the coal was up on a high level was to keep it up at a reasonable height, and run it down by gravity into the ship's hold. The present system of coal loading by means of expensive power hoists was very analogous to the celebrated military operations of the noted Duke of York, who marched his men up to the top of the hill and then marched them down again.

Mr. R. P. **MORRISON** thought the authors, in the way they had arranged their machinery at the Rothesay Dock, had done away with one of the points which he had always understood was a great feature of electric power, namely, flexibility. He presumed from what was stated in the Paper that each hoist had to have its own separate generator. If at any one particular time it was only required to work one coal-hoist, it was necessary to run the main generator and a fly-wheel generator. Supposing that the vessel being coaled was a 4,000-ton vessel, it would take two shifts, and the vessel would be twenty hours under the tip. Out of the whole

(Mr. R. P. Morrison.)

of that time the fly-wheel generator would be used for hoisting and tipping for only six hours, that is, taking acceleration and retardation as equal, so that the power would be wasted for fourteen hours; the fly-wheel being driven round for no effective work for that length of time. If three coal-hoists were being dealt with, as would ultimately have to be done, it would be necessary to have two sets of generating plant working, and it was impossible to move about from one to the other; and if there were thirty hoists on a dock, it would be necessary to have so many more generating plants that the whole thing would be confused.

Dealing particularly with the pecuniary side of the question, the authors had compared the tip at the Rothesay Dock with an old tip at Newport. The latter tip worked on a two-stage principle. Only the lower half of the stroke of the tip had any constant pressure; and the top half of the stroke was obtained from one plain ram without constant pressure. It was therefore not working economically, and instead of using 280 gallons, as it did at present, should only use 220 gallons. Modern tips similar to those in use by the Great Western Railway, the Midland Railway and other railways were manipulating 20-ton gross loads through 46 feet and tipped to an angle of 45°, with only about 220 gallons to do the work. Reducing the figures in Table 4 (page 20) to conform with those figures, the cost came down to 14*s.* 10*d.* But then the question of 9*d.* per 1,000 gallons had to be taken into consideration. Mr. Macaulay for Newport had given his costs for pumping as 2·08*d.* per 1,000 gallons in 1906. Adding to those costs such expenses as depreciation, interest on capital, insurance, and establishment charges at the rate of 10 per cent., the figures were increased up to 4·66*d.* If those figures were inserted in the Table which the authors had given, the cost per 1,000 tons of coal tipped was 9*s.* 11*d.* Further, if the figures in Table 4 (page 20) were adjusted to conform to both reduction in water-consumption and cost per 1,000 gallons, the cost of shipping 1,000 tons of coal at 46 feet lift would be 7*s.* 8*d.* against the authors' figure of 10*s.* 11*d.* at Rothesay Dock. But the 10*s.* 11*d.* was not the price at which the authors were doing the work at the present time. It was the price at which they were going to do it. He prophesied that, if the authors were asked the question in another two years' time, they would be very pleased to answer that it was costing them only $1\frac{1}{2}d.$ per unit for electric power at Rothesay. [*See also page* 114.]

Mr. E. KILBURN SCOTT said that about ten years ago he had had some experience in connection with a dock crane installation on the Thames, in which a reversible booster was installed in connection with a storage battery. It worked exceedingly well and he believed was the first installation of the kind in this country, although a similar installation had been put to work in Germany. He thought that for smaller dock installations there was a good deal still to be said for the adoption of the storage battery, because it was always ready and did not run down in the night. With fly-wheel storage if loading was not being done at night the machinery would come to a standstill, and the next day he presumed it would take some time to get the fly-wheel up to the proper speed again. For example, his experience as manager of the Brennan Mono-rail car at the White City was that it took about an hour to run the 15-cwt. gyroscope fly-wheel up to proper speed before the car could be used. He would like to ask the authors how long it took to get their fly-wheel to run up to full speed. Mr. Patchell had informed him that it took twenty minutes to get the storage fly-wheel at the Ferndale Colliery up to full speed. Now this long speeding up must of course mean a considerable energy-loss, and there was no such analogous loss with either the hydraulic accumulator or the electric storage battery.

He noticed that the authors had thought of putting their fly-wheel in a vacuum with the idea of reducing the air-friction. Such air-friction loss on high-velocity fly-wheels for storing energy was a serious matter. The gyroscope fly-wheel on the Mono-rail car, to take a well-known example, could not run at full speed except in a good vacuum. When the vacuum dropped to about 20 inches it was necessary to stop because the motors ran hot, simply because

(Mr. E. Kilburn Scott.)

of the extra energy required to overcome the friction of the air. Here again was a loss in fly-wheel storage which had no analogy in either hydraulic accumulators or the electric storage battery. There was a great deal still to be said for the storage battery, because it was more akin to the ideal of the hydraulic accumulator than fly-wheel storage could ever be. On a question of safety the fly-wheel was certainly not so safe as either of the other forms. High-speed shafts carrying heavy fly-wheels were peculiarly liable to fracture, and it would only require one storage fly-wheel accident to jeopardize the further use of that form of storage. One point which he thought could be claimed for the fly-wheel storage as against the electric storage battery was that the latter required the commutator type of machines as dynamos and reversible boosters, etc.

He noticed that the authors had not taken advantage of the three-phase system with its robust motors, but they had laid down direct-current plant. It would be interesting to know exactly why direct current had been preferred. Was variable-speed requirement the reason ?

Into the controversy as to whether hydraulic or electric power was the best, he did not propose to enter, but it was conceivable that the best solution might in some cases be obtained by a combination of the two. About eight years ago he saw some overhead cranes at the Great Western Railway works on which electric motors were used for the longitudinal travel and the traverse, but hydraulic power was used for the lifting hooks. The engineer in charge said they could place the locomotives with greater accuracy with the electric lift. The water was, of course, pumped by an electric motor. It seemed as if the best solution of power transmission in gassy coal mines was going to be by a combination of electricity and compressed air; so also in crane work there might be room for both hydraulic power and electricity.

Regarding electric capstans, the firm he represented in 1901 sent out about half a dozen to the Bahia Blanca Railway, and they had been a great success. They were of the turntable type, and a considerable number of the same type were afterwards supplied to the Antwerp Docks after an exhaustive test of various makes. The starting switch was the most delicate part of an electric capstan, and it might be worth mentioning that although the capstans at Antwerp were built by the International Electric Company of Liége, the design of the special switch-gear used was due to Mr. Walter F. Jones.

Mr. JOHN A. F. ASPINALL, Past-President, thought the question to be decided was one which really depended upon the first cost plus the maintenance. The Lancashire and Yorkshire Railway had a large amount, not only of hydraulic but of electrical machinery in use. The former had been employed at the docks and goods stations. It was not costly to install, and had been most economical to maintain. The Lancashire and Yorkshire Railway had a number of electrical capstans and cranes, and their installation had been quite justified, because they were used in places where the load was extremely variable, where sometimes a capstan had to haul one wagon and sometimes twenty wagons. Where the load was more constant, hydraulic capstans might be used. The cost of pressure water had a very important bearing on the case. The installations of machinery at some places were not sufficiently great to warrant the erection of pumping plant, and in this case the power had to be purchased from neighbouring sources of supply. Very small figures had been mentioned by some of the speakers on the cost per 1,000 gallons, but he could quote two cases where the one vendor required 1*s*. 4*d*. per 1,000 and the other 2*s*. 4*d*. per 1,000 gallons. At both of these places electrical working would be cheaper than hydraulic, even if the original machinery cost more. The authors had not yet had sufficiently long experience to state whether the plant at the Rothesay Dock was really more economical, so far as maintenance was concerned, than hydraulic machinery. In dealing with coal in large quantities by means of hydraulic power, very little wear and tear was experienced, but engineers did not yet know what the wear and tear was going to be upon the rather faster running electrical machinery and upon the chains, because

(Mr. John A. F. Aspinall.)

the coal dust had an immense wearing influence which gave them a very short life.

There was one point in connection with the wagons to which a speaker referred, to which he would like to direct attention, namely, that it must not be forgotten that nearly all the wagons which carried coal were the property of the traders. There were in England somewhere about one million wagons altogether, about half of which belonged to the traders. The Lancashire and Yorkshire Railway Company owned about 34,000 wagons, and upon that line there were about 54,000 wagons belonging to the traders. Some of the traders were very unwilling to change their wagons, because they used them on one day for coal which was going for land sale, and on the following day for coal which was going to the docks to be shipped. The smaller wagons were better for the land sales, but the large colliery proprietor would rather have the larger wagons for shipment of coal and for tipping. As a result of this desire to use wagons carrying 20 tons of coal, many of the coal-hoists on the East Coast had been constructed to lift a gross load of 32 tons, like the Rothesay Dock hoists, and there was no doubt that as dock machinery was thus modernized the use of higher-capacity wagons would rapidly extend. At the East Coast ports, where very large quantities of coal were dealt with, the hoists had to deal with wagons of varying capacity carrying sometimes 8 tons, sometimes 10 tons, and sometimes 20 tons. All those were varying weights, and the weights to be dealt were even more varied than that, because when the coal had been tipped the empty wagon had to be lifted and put back into its position, and that again was a varying weight. The hoists had to deal with such changes in weight as a 5-ton empty wagon which weighed 13 tons when loaded; or an empty wagon weighing 10 tons, which, when loaded, weighed something over 30 tons, when 20-ton loads of coal were being shipped. In that kind of way there was an immense variation in the weights to be dealt with, which resulted in the hydraulic hoist becoming a somewhat expensive machine on account of that variation, the same amount of pressure water being used in each case. In that class of work the electrical appliance which adjusted itself absolutely to the load was probably going to show some points in economy which might compensate for the greater cost of maintenance, if there was a greater cost of maintenance found to exist at some period. He thought it was very doubtful whether anybody could make an absolutely broad statement at the present moment which would enable new dock builders to say they ought to equip their docks either with the one form of machinery or the other. The circumstances of each case would have to be considered by themselves.

The **President** read a short portion of a communication which had been received from Mr. Macaulay (page 102) dealing with the question of cost per 1,000 gallons, about which a good deal had been said in the course of the discussion.

The impression that had been left on his mind by the discussion, which had been of a very interesting and sustained character, was that the question would have to be further discussed in a year or two's time. The general result up to date appeared to be that there were many purposes for which hydraulic power was particularly well suited, while there were many purposes for which hydraulic power had been used in the past, because of its comparative flexibility at the time, which could now be better done electrically; but certainly it could not be said that at the present moment the question was finally settled as to what system would be adopted in the future. Mr. Roger Smith might be right, but prophecies were always dangerous.

Mr. **Walter Dixon**, in reply, said that it was a great satisfaction to the authors that their Paper had elicited such an interesting discussion. He regretted the omission of so many details about which various speakers had remarked, but it would at once be obvious that it was impossible without turning the Paper into a volume to furnish a full description of the various plant installed. Perhaps, it might be possible at a later date, when the dock was fully equipped, to furnish further particulars. Meanwhile, he thought the purpose which the Paper was intended

(Mr. Walter Dixon.)

to serve had been recognized, namely, that of marking a stage in the Electrical Equipment of Docks which had been declared on two recent occasions as impracticable, if not impossible. It had further furnished an opportunity of bringing before the Institution data as to the first complete dock-equipment of its kind, and for which four new and distinct types of plant had been designed, and for the first time employed, namely, Generating Plant; Coal-Hoists; Capstans; and Turntables.

The troubles incidental to all new machinery had not been absent; at the same time, they had been of such a particularly mild order, and so few, that from a practical point of view, they had been non-existent. From the first starting, the plants had shown such entire suitability and reliability for the work for which they were intended, that it required no keen insight to prognosticate that electricity for all dock purposes would for the future as surely replace hydraulics as hydraulics had replaced other forms of power.

Reliability.—It had been suggested that a sufficient time had not yet elapsed to be able to speak with confidence as to the relative reliability of electric and hydraulic machinery. While it would require sixty years' actual working to realize that the plant would last sixty years, an inspection meanwhile by any of the practical gentlemen who had taken part in this discussion would convince them that it was likely to work long enough to satisfy all reasonable requirements.

Relative Power-Costs.—Another important point which had been raised was that of the relative cost of electricity and hydraulic power. In the Paper the authors showed that the costs over the last three years, during which the dock had been partially at work, had satisfied them that, when fully equipped, the cost of energy would not exceed 1*d.* per unit, and there the matter must stand. In mentioning this 1*d.* per unit, he would have it understood that this included all charges, that is:—Labour; Fuel; Oil; Stores; Superintendence; Interest and Depreciation on Plant and Buildings; Repairs and Maintenance; and in fact, all charges incidental to the plant and its working. It had been suggested by one speaker that the authors had halved the actual and probable figure; but this was not so, as an analysis of the figures given in the Paper clearly showed. Leaving this, and coming to the cost of hydraulics, they were on far less certain ground; in fact, they did not appear to be on ground at all; they were on shifting sand. He had had the Transactions of the various Technical Societies during recent years searched for statements as to the costs of hydraulic power at docks, and it was not without surprise that he found that only three or four statements had ever been made on the subject. These he had recorded in Table 8 (page 82), together with the information he had been able to obtain privately.

The points he would make with regard to Table 8 were the absence of any common basis:—Some presumably included Capital Charges; some did not. Some presumably included Transmission Costs, some did not; and he would suggest to hydraulic engineers that, before commencing to quote comparative figures, they should at least decide on some common basis, including the items mentioned above as being included in the Electrical Costs.

A second point with reference to this Table was, that, with the exception of Newport, the lowest figure was 8·41*d.* per 1,000 gallons, and the highest more than double this, and that the figures of:—8·41*d.*, 12·82*d.*, 17·67*d.*, had hitherto had no word of objection raised to them. They had been accepted without comment. The only figure which had been the subject of criticism was that of 2*d.* per 1,000 gallons, and this even Colonel Tannett-Walker objected to, and wished to double. The amended figures given to-night, both for Newport and Swansea, made it obvious that they were not on a common basis. It had been suggested that in taking 9*d.* as a basis, the authors had doubled the actual cost; but he asked what grounds there were for any such suggestion. He contended there were none.

Relative Efficiencies.—Leaving the question of relative costs, they were brought to what was perhaps more important, namely, relative efficiencies, for even were it shown that hydraulic power

(Mr. Walter Dixon.)

TABLE 8.

Cost of Hydraulics at Docks per 1,000 Gallons Water.

Date.	Reference.	Place.	Pressure.	Cost per 1,000 gal.	Including capital charges.	Including distribution charges.
			Lb.	*d.*		
1904	Proceedings. I.Mech.E.	Middlesbrough	750	12·82	Yes	No
1906	I.Mech.E.	Newport	750	2·0	No	No
1907	Inst.C.E.	Glasgow	?	17·67	?	?
1907	Inst C.E.	Middlesbrough	750	12·82	Yes	No
1907	Inst.C.E.	Swansea	750	8·41	? Yes	?
			From private sources.			
1907	A	—	750	12·0	Yes	No
1907	B	—	750	20·0	Yes	? Yes
1907	C	—	750	8·0	?	?
1907	D	—	750	9·3	Yes	No
1907	E	—	750	18·0	Yes	? Yes

could be produced as cheaply as electric power, it would still be necessary to show that one could be as efficiently used as the other. On this score their hydraulic friends were in a hopelessly impossible position. It was common knowledge that, with properly designed electrical plant, the power used was a direct measure of the work accomplished, this result being obtained automatically and without manipulation. Such was not the case with hydraulic power, and they contended for the correctness of the statement made in the Paper (page 32), and to which exception had been taken, that:—"The supply of water, in the case of hydraulics is always more than the quantity required, and therefore some of it is wasted; this waste may vary from 5 to 50 per cent." As a matter of interest, he had prepared two or three diagrams designed to illustrate this. They were not scientifically correct, but erred in giving advantages to hydraulic power, inasmuch as they assumed the efficiencies to be the same, whereas electricity would, under all conditions, have an advantage.

Fig. 25 (page 84) dealt with a 32-ton Coal-Hoist fitted with three rams each of 11 tons, working with a minimum load of 10 tons.

Fig. 26 dealt with the case of an actual Coal-Hoist recently supplied by one of the principal makers in the country, being fitted with one ram, and having a maximum load of 20 tons. Incidentally, it might be of interest to know that the efficiency of this hydraulic hoist was at *full load* about 10 per cent. less than that obtainable with an electric hoist under *varying loads.*

Fig. 26 dealt with a Capstan under various loads. The diagram took no account of the relative number of revolutions which were made by the old type—both hydraulic and electric—and the new "Clyde" type of Capstan.

In dealing with this question of efficiency, Mr. Ellington made an important statement in reference to the London Hydraulic Power Installation (page 51):—"The quantity of water which was registered in the meters had for years past exceeded 95 per cent. of the quantity pumped into the mains," from which the deduction was made that the percentage of loss was extremely small, or, inversely that the efficiency was extremely high. This might be

(Mr. Walter Dixon.)

Fig. 25.

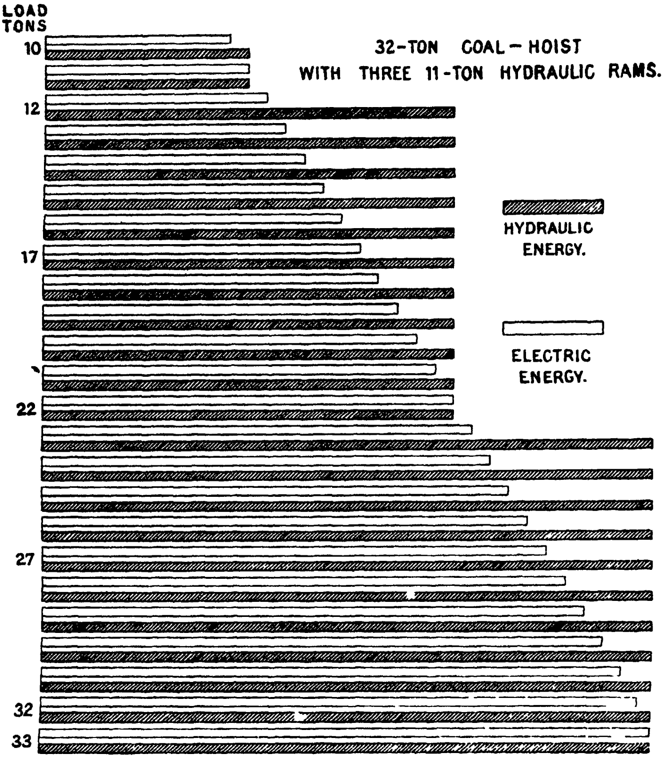
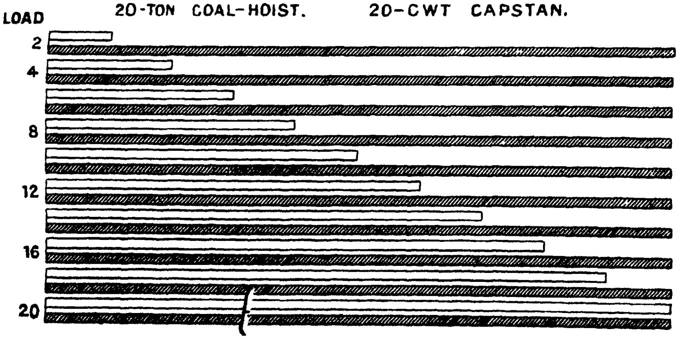
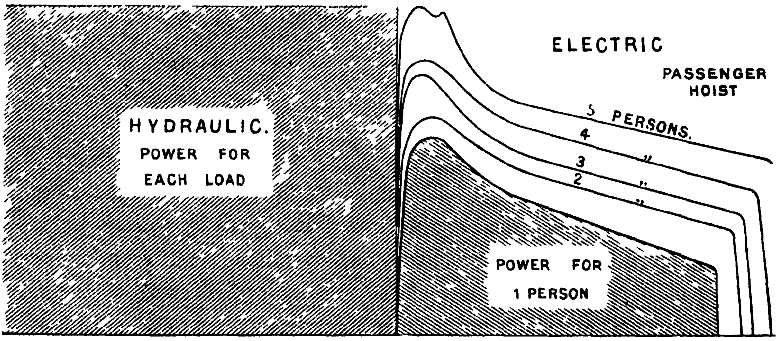


Fig. 26.



granted, and the London Hydraulic Power Company were to be congratulated on the result, but what about the consumers? They would surely have a different story to tell. He had prepared a Load Diagram, Fig. 27, of a newly-erected electric passenger-hoist in the building in which his office was situated in Glasgow. The diagram represented the amount of current used with different numbers of passengers, showing once more that the power varied automatically with the work to be done. He had represented on the diagram the relative power which would be consumed had the hoist been a hydraulic one, and the result showed that the power which would be expended on the five journeys, under the differing conditions, that is, with one, two, three, four, and five passengers, would in the case of hydraulics be two to three times more than in the case of electricity. Electricity for hoists' purposes could be purchased at 1½*d.* per unit, and hydraulic power at about 1*s.* 6*d.* per 1,000 gallons. Therefore, while the Hydraulic Power Supply Co. might get 95 per cent. efficiency, the user of hydraulic hoists would be paying, and in actual practice did pay, three to four times more for the work done hydraulically than electrically.

FIG. 27.



Leaving, however, the question of domestic supply, and coming back to the question of dock supply, he would point out that if it could be shown that hydraulic power could be supplied as cheaply as electric power, the advantage was still largely with electricity.

(Mr. Walter Dixon.)

Power Stations.—Coming next to the question of Power Stations, Mr. Ellington was good enough to make a diagram showing the relative cost of the working of a hydraulic station and an electrical one under maximum loads (page 48), which point was one on which Mr. Ellington had on other occasions expressed himself clearly and strongly. He would mention, however, that with the advent of their application of an accumulator, which was as efficient and effective as the hydraulic accumulator, conditions were altered, and any advantage which hydraulics might hitherto have exclusively possessed were now gone. He had thought of making a counter diagram, but had refrained, inasmuch as the factors on which such diagrams should be based—both as referring to hydraulics and electricity—could not be regarded as universal, the character of the load in each case calling for special consideration.

The relative suitability of electricity and hydraulics had been amply dealt with, and perhaps need not again have been referred to, except to point out in reply to Mr. Ellington that in undertaking the electrical equipment of Rothesay Dock, the point with regard to the coal-hoists was not so much one of economy as "possibility." It had been already recognized in 1905, what has now become practically universally recognized, that on the score of economical working, electricity for docks—where applicable—was pre-eminent. With such a consensus of opinion as was voiced by Sir William Matthews in 1907, as to the unsuitability of electricity for certain kinds of machinery, it was not without interest to the authors to have shown that electricity was not only possible, but probably better, and certainly not less economical.

Frost and Weather Conditions.—He would not labour the question of trouble during times of frost, except to draw the attention of Mr. Clarence Ridley, who made a point of this (page 53), to two statements which had been made during recent conferences:—

(1) In 1895 * it was pointed out that "during severe frost, the water-consumption at Bristol had gone up in the course of a week

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* Proceedings, I.Mech.E., 1895, page 383.

or ten days to double the normal amount, and had continued so for five or six weeks, and it was wondered what percentage of water was pumped to waste for maintaining circulation during the frost."

(2) Coupled with this, he would refer to the statements made at the Engineering Conference in 1907, "that at the various docks, gas-pipes are laid and gas-jets applied to various parts of the machinery which are exposed to the effects of frost."

If, therefore, trouble and stoppage through frost could only be prevented by an otherwise useless waste of water, whether costing 2*d.* or 12*d.* per 1,000 gallons, and by the installation of gas-pipes and gas-jets which might only be needed one day per year, but which were rusting or leaking and giving trouble during the whole 365 days, the frost question was not such a bogy as some would have them believe. It has been justly said that electricity had troubles on account of damp; and there was no doubt this was so. Probably a worse position than the Rothesay Dock on the Clyde was not possible in this country, but it has been possible to overcome in a satisfactory way the whole or at least the most of such incidental troubles, so much so that, as stated in the Paper, no stoppage due to electrical causes had from the first occurred to interrupt the regular working of the dock. Bearing on the same point, the current issues of *Engineering* described two types of Scherzer rolling lift bridges, which had recently been erected over river channels, which for bad weather conditions compared with Rothesay Dock. The electrical plant and equipment in both cases were designed by and the work carried out under the superintendence of the speaker's firm, and the special attention which had been paid to the design and suitability of the various machinery employed had resulted in perfect working and reliability, which could not be surpassed by hydraulics or any other form of power.

Capital Costs.—With regard to the question of the cost of plant, in considering this matter, the authors refrained from making reference to Capital Cost beyond the statement made on page 34, namely:—"That it is probable there need be no appreciable difference in the capital cost of an electric and hydraulic station

(Mr. Walter Dixon.)

when fully equipped for the complete dock installation for power and lighting," and to this statement they adhered. No figures which they could have put before this Institution would have been immune from criticism, whether they had referred to electricity or hydraulics, and as the nature of the work to be done in every dock was or might be essentially different as regards loads and conditions, each case required to be separately dealt with.

"Cheap" Work.—He associated himself entirely with the various speakers who referred to the disastrous effects of the low class of work which was becoming more and more prevalent under the absurd lengths to which competition was being systematically carried on in this country. Much of the engineering genius of this country was devoted to the making of a £100 article pass the terms and conditions of a specification issued with the intent of getting a £200 article. It was, he believed, universally admitted by all people qualified to judge that, except in very special cases, it was not possible to draw up a specification for machinery or plant, through which the proverbial "coach and four" could not be driven. Notwithstanding this, and the advertisements of Public Bodies "that the lowest offer will not necessarily be accepted," such offers were in many cases perforce accepted, and the occupation of the inspecting engineer became rather that of a policeman than an engineer.

At the Cardiff Meeting,* one of the speakers stated that "for every breakdown hydraulically, he had had one hundred breakdowns electrically." Such a statement, while made figuratively, might be accepted literally, for no branch of the Engineering Industry had suffered more than Electricity from: (1) The application of cheap plant; (2) The application of unsuitable plant; (3) The application of ill-designed plant; and (4) A combination of the whole three faults. He imagined that the speaker in his "hundred to one failures" had been labouring under condition 4.

Working Speeds on Hoists.—In regard to the question of the plant, in detail, he would like to thank the President (Mr. Aspinall) for the interesting particulars he had given respecting the possible working time of coal-hoists and coaling cranes. It was of particular interest, inasmuch as it was on the lines of, and arrived at practically the same results, as the authors in deciding the speed at which their coal-hoists should work. It was possible to have designed the hoists to work at any speed, but it was clear to them, as he ventured to suggest it was hardly clear to Colonel Tannett-Walker in his criticism, that the increase of hoisting speed in a coal-hoist from 100 to 200 feet per minute, while it increased the maximum power requirements 100 per cent., did not by any means increase the useful output of the hoist by more than a small percentage. He had made observations on this point at the Rothesay Dock a few days ago. Coal was being shipped in wagons containing about 8 tons each, and raised to a height of 25 feet at the rate of sixty-two wagons per hour, which speed he might say, in reply to a question of Colonel Tannett-Walker's, could, so far as the machinery was concerned, have been maintained for an indefinite period. Here were conditions surely fast enough to meet anybody's requirements, and at a lifting speed of 100 feet per minute. The President had shown that the useful time of a coal-hoist only occupied say 50 per cent. of the possible time. Of this 50 per cent. useful time, the hoisting in the above instance occupied say 25 per cent., or 12½ per cent. of the possible time. To have increased the cost by doubling the power and doubling the speed to 200 feet per minute, would therefore not have increased the coaling capacity of the hoist 100 per cent., but something under 10 per cent.

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* Proceedings, I.Mech.E., 1906, Part 3, page 497.

That no advantage was derived from the relatively high speeds of hoists was obvious from the figures of coaling performances enumerated by Colonel Tannett-Walker. In mentioning a coaling performance, size of trucks, height to be lifted, class of vessel, etc., were required to give the figures relative importance, and all the figures mentioned were capable of easy attainment by electrical coal-hoists, but he commended a coaling speed of sixty-two wagons per hour, as mentioned above, to their hydraulic friends, not as a record, but of what it was possible to do with what was admittedly a low lifting speed of 100 feet per minute.

(Mr. Walter Dixon.)

Mr. Baxter would deal with other points, and the replies taken together would be seen to cover all matters of principle raised in the discussion.

Mr. GEORGE H. BAXTER said that, in opening the discussion, the President had referred to some useful formulæ expressing hydraulic power in terms of horse-power, and in Board of Trade units of electric power. To convert any given quantity of water at any given pressure into the equivalent number of Board of Trade units of electricity and *vice versa*—the following formula which he had always employed in such calculations might be found useful, thus:—

If U = Units, G = Gallons used per hour, and P = Pressure per square inch, $U = G \times P \times 0 \cdot 0000087$. From this one found that 1,000 gallons of water at 750 lb. pressure per square inch equalled 6·525 Board of Trade units, and if electric power cost 1*d.* per unit, the equivalent cost of 1,000 gallons of water at the pressure of 750 lb. per square inch would be 6·525*d.*

Most of the speakers who had taken part in the discussion referred chiefly to the cost of producing power in the generating station, but altogether avoided the very important question of the efficiency of the appliances by which the power was utilized. Whether one could produce electrical energy at less cost than one could buy it, did not in the slightest degree affect the point at issue. Let them suppose that the current was supplied from an outside source at the price of 0·8*d.* per unit. As a matter of fact, they would now be paying less than that if current were supplied by the Corporation of Glasgow to Rothesay Dock at the same rates as those charged for the new dock and quays at Yorkhill. Allowing for conversion in the motor-generators, the actual cost at the coal-hoist switchboard in the power station would be 1*d.* per unit. He would take the cost of 1,000 gallons of water at 750 lb. pressure as being 9·3*d.*, which, notwithstanding what had been said, seemed a reasonable figure for a small installation such as that at Queen's Dock, or as would have been necessary at Rothesay Dock, had hydraulic power been adopted. As mentioned by

Mr. Binns in his Communication (page 95), the cost of power largely depended on the output and load-factor. The power might be doubled or trebled with the same staff, the only additional cost being a proportional increase for coal. Now the electrical equivalent of 9·3*d.* per 1,000 gallons was 1½*d.* per unit. That is to say that at 1*d.* per unit electric power cost two-thirds of the equivalent hydraulic power.

Fig. 28.

Comparative Efficiency of Electric and Hydraulic Coal-Hoists.

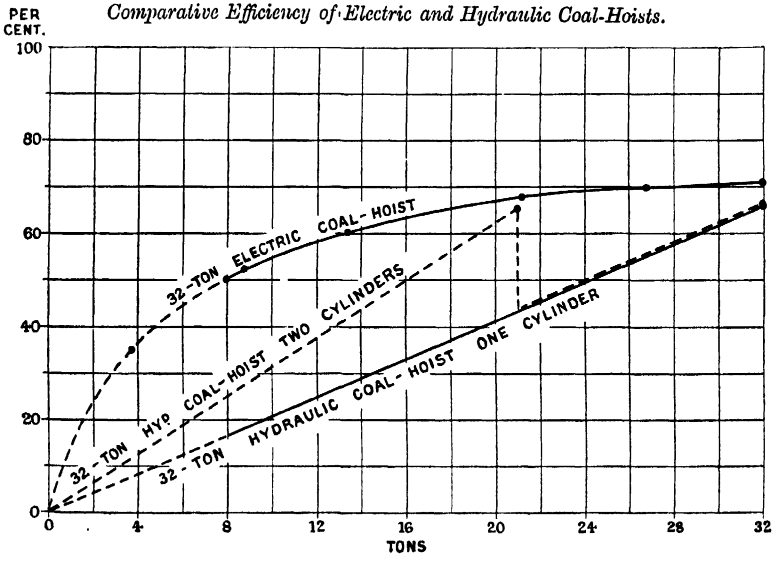

Fig. 28 was a diagram showing curves of efficiency for a 32-ton electric coal-hoist and a 32-ton hydraulic hoist, worked by one ram, and, shown in dotted lines, a 32-ton coal-hoist worked by two rams, one for 21 tons and an auxiliary ram for 11 tons. This proportion was chosen to suit the sizes of wagons, most of which were under 21 tons; and while it was necessary to have the 11-ton ram, it would probably be seldom used. Now comparing the curves, one found that between usual loads of 10 to 20 tons, the efficiency of the single-ram hydraulic hoists was only about 50 per cent. of that of the electric hoist, and the efficiency of the two-ram hydraulic

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hoist was 70 per cent. of the electric hoist, but it was shown that the cost of electric power was only two-thirds that of hydraulic power, and as the efficiencies showed that the amount of power used was in the single-ram hoist 50 per cent., and for the two-ram 70 per cent., the cost of electric power would in the first case be one-third, and in the second case rather less than one-half the cost of the hydraulic power required to do the same amount of work.

Now, in regard to cranes versus hoists, as Mr. Aspinall indicated in his remarks, the quantity of coal shipped in a given time was largely dependent on the rate at which it could be trimmed. In the case of the hoist, this occupied 12·25 per cent., and of the crane 8·24 per cent. of the time, which seemed to indicate that more coal was shipped by the hoist than by the crane. It was well known that a hoist could ship coals at double the rate at which a crane could, and where large steamers of say 5,000 to 7,000 tons had to be loaded, full advantage could be taken of the quick loading power of the coal-hoists at Rothesay Dock, as trimming should take relatively less time than in the case of smaller boats. The only advantage a crane had over a hoist was that the softer kinds of coal were not so liable to be broken up in emptying the wagon direct into the hold of a vessel, and cranes were sometimes preferred to hoists by shippers and consignees on that account. In this connection Colonel Tannett-Walker wanted to know if the speed of shipping a wagon per minute by the electric hoist could be maintained for more than 30 minutes. There was no reason why it should not continue for any length of time shipping at this rate. The authors thought that hoisting speeds of 150 to 200 feet per minute were excessive, entailing as they did heavier power plant, more damage to wagons, larger pipes and greater wear and tear on the hoist and all plant, than a moderate speed of 100 to 120 feet per minute, which was quite sufficient to enable coal to be shipped at the rate of one wagon a minute. What did the hoisting speed matter however, so long as this rate of shipping coal could be maintained? If an increased rate of shipment was desired, the proper method was to adopt larger wagons, as had been done to some extent in the North. Regarding time lost in tipping, this need not exceed more than two or three seconds. Bumping or "kicking" the wagon after being hoisted should be discouraged as far as possible, as, in addition to causing serious damage to the wagons, it threw a very severe stress on the framing of the hoist which was subjected thereby to very heavy shocks; indeed, half the accidents to men employed were due to lumps of coal being thrown out of the wagon by this barbarous process.

Colonel Tannett-Walker remarked that the authors had thrown down a challenge to Hydraulic Engineers. This had not been their intention, but if anyone regarded the Paper in that light, the authors trusted it would be as a friendly challenge. Their principal object had been to bring to the notice of the Members and to others who had to deal with Dock Equipment, an account of what was being done on the Clyde, in the development of electric power as applied to this class of machinery with a view to its improvement in working, in economy, and efficiency. Up to the present time, these were the only coal-hoists in the world which were worked by electric power on the system adopted, and the fact that it had proved such a marked success was the reason that they ventured to think it might at least be interesting to the Members of the Institution, and perhaps be deemed worthy of their consideration.

The hydraulic crane referred to was one of seven made for Princes Dock in the year 1901 by Messrs. Alex. Chaplin and Co., of Govan, and was quite up to date. The electric crane with which it was compared was also made for Princes Dock in 1901 by Messrs. Stothert and Pitt, of Bath, so that as regards age both cranes were practically alike.

With regard to capstans, anyone who expected to get a dock capstan for something less than £70 would not have his sorrows to seek if he had to do with its working and maintenance. The price of the marvellous capstans alluded to by Colonel Tannett-Walker was somewhere between £70 and £200, but rather nearer the latter than the former figure.

As regards fly-wheels, there was no reason why they should not be made large enough in size and number to give the same horse-

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power as at Barry, where there were 17 hydraulic accumulators. It had already been shown that cost of power for an electric dock-equipment was less than half that of the power required for a hydraulic equipment to do the same amount of work, and the problem of an electric installation was therefore not quite such a serious matter as it would seem. This might not perhaps apply so much to Barry, where the wagons were presumably all of the same size, and the coal-hoists were being nearly always worked at their maximum efficiency, as to other ports such as Glasgow, where the sizes of coal wagons varied considerably. The quantity of coa shipped per annum depended entirely on the state of trade, which last year was much interrupted by the lamentable lock-out of shipyard workers, but the point they wished to emphasize was that the electric coal-hoist was capable of shipping coal quite as rapidly as the hydraulic coal-hoist, and at less cost.

Communications.

Mr. JOHN BARR wrote that he thought the "crux" of the question so far as coal-hoists were concerned was manifestly the cost of hydraulic power per thousand gallons. This varied under different conditions and circumstances, and perhaps the authors could give the cost of hydraulic power as found, say, at Princes Dock, Glasgow, stating whether the water was returned to the tank at the engine-house in return-pipes and the quantity and cost of the making-up water due to leakage. Hydraulic capstans could be made and had been made on the loose-head principle. One important item that was not touched upon in the Paper was the first cost of the various appliances, and it would be interesting to know how this compared with the costs of similar hydraulic machines. There was also the question of comparative costs of attendants' wages. He would like to know whether the men required to be more highly paid and whether a fewer or a greater number were required.

It was generally agreed that suspended loads, such as on coal-hoists, were not so safe as those with direct-acting hydraulic rams. It was stated (page 33): "That no stoppage due to electrical causes has occurred to interrupt the regular working of the dock." From this it might be inferred that there had been stoppages due to causes other than electrical, and it would be interesting to know the reason of the failures. It was not stated whether the cradle of hoists was counter-balanced or over-balanced, or whether there was any provision for cutting off the current in the event of the cradle being allowed to overrun the proper height. Maintenance for two years had proved so far satisfactory, but it was of course a question of experience as to what the comparison would be fifteen or twenty years hence.

Regarding electric cranes, no comparison was given in the Paper as to the economy of these as compared with hydraulic cranes. If any information on this point were available, it would be useful to have it. He noticed that the names of the makers of the various machines were not mentioned. He thought that the authors were to be congratulated on the success of the carrying out of a new and difficult problem in an ingenious and efficient manner.

Mr. A. BINNS wrote that the cost of power production, whether hydraulic or electric, depended very largely upon the annual output and the load-factor. Even when cases were fairly comparable in these respects, it was necessary also to consider whether the generating plants were equally modern and represented approximately the same capital outlay. Due regard must also be had to the local prices of coal and labour. It was no matter for surprise, therefore, that widely divergent figures were quoted for running costs. From the writer's personal knowledge of annua running costs at eight hydraulic-pumping stations, and five electric-generating stations, he was convinced that, under equal conditions, electric and hydraulic power were produced at equal cost.

(Mr. A. Binns.)

With regard to the distribution of power, either hydraulic or electric, he was of the opinion that there was little to choose either in cost or reliability within the comparatively short distances which obtained on a dock estate. With long-distance transmission, however, electric power had a great advantage with the adoption of high-tension alternating current and a transformer station. With regard to the machinery for which the power would be used on a dock estate, he thought it would be conceded that the electrical machine of equally good class and capacity would prove the more expensive in first cost. Regarding the power consumption, undoubtedly the electrical machine had a very considerable advantage. It rarely occurred in actual dock-work that a hydraulic machine, a crane for instance, was used regularly at anything like its full load, and he thought, generally speaking, there would be a saving in power consumption in favour of electrical appliances of at least 20 per cent.

Referring to costs of driving, oiling, stores, and repairs, he thought that the hydraulic machine held a slight advantage. It was also more "fool-proof," and could be operated and attended to by a cheaper class of labour. With regard to the important point of reliability, he did not think there was a great deal to choose between the two systems in cases where the machines were in regular use and well looked after, but in the case of the machines for heavy operations, used only intermittently, the hydraulic appliance would undoubtedly have an advantage. Generally speaking, therefore, with regard to dock machinery, he considered that, notwithstanding the increased first-cost, electrical plant was preferable in cases of regular running, such as the operation of grain elevators and conveyors, compressors for refrigerating purposes, light cranes, lifts, and workshop driving, in fact all cases where the total annual consumption of power was so considerable as to make the saving in power charges commensurate with the increased first cost and cost of maintenance, etc. On the other hand, he was of the opinion that there were still great mechanical advantages about hydraulic machinery for intermittent operations, especially in exposed situations. This would apply to gate machinery, sluices, capstans, swing bridges and heavy cranes.

To refer more particularly to the Paper, he considered that it was frankly an *ex parte* statement from the electrical engineer's point of view, and some of the comparisons appeared to be of little use, as pointed out during the discussion. The various remarks upon the "Clyde" capstan would scarcely appear to be generally applicable. The fast rope might be permissible at the Rothesay Dock, where the area of operation for each capstan was well defined, but for general purposes, such as working ships and craft there would appear to be objections, and, as far as he could understand, the fast-rope principle had not been adopted for the pier-head capstans. It was rather difficult to understand the construction of the capstan from the general description, and he would like to ask what happened when the capstan was put to pull a wagon which had the brake on? A one-ton capstan in general dock-work probably consumed on the average about six pennyworth of power per week, and therefore a saving of say twopence per week was not a factor of great moment. With a hydraulic capstan, if one attempted to move too heavy a load, the result was that the capstan merely "sulked," whilst the average electric capstan went into "hysterics."

The adoption of the fly-wheel in conjunction with the generators for the coal-hoists appeared to be an ingenious and successful arrangement, and, he thought, justified the claim of the authors that it was the equivalent of the hydraulic accumulator, although a very small one. Both expedients were excellent for taking peak-loads over very short periods. What one wanted, however, for cheap power-production, either hydraulic or electric, was an inexpensive accumulator of vast capacity to enable one at all times to run the steam-plant on a high load-factor.

Mr. H. H. BROUGHTON wrote that in tackling the problem of dock electrification, a field had been entered which was generally admitted to belong to another branch of the profession. Electrical engineers had had to overcome thirty or forty years' prejudice. He felt that the fault was largely their own, for quite early in their history they had divorced themselves from their

(Mr. H. H. Broughton.)

brethren. They had surrounded themselves with mystic signs, with impossible theory and with equally impossible practice. The sealing-wax and string stage had passed away and the progress made in things electrical during the past ten years was really due to improved knowledge of materials and to improved mechanical construction.

The plant described in the Paper therefore was well worthy of the careful consideration of those dock engineers and harbour authorities about to extend or to modernize their equipment. In his opinion the Institution was to be congratulated on its good fortune in having had such a valuable contribution to the Proceedings. The Paper showed that electric driving was well suited, as regards first cost, reliability, and working cost, to the conditions which prevailed at docks. The general impression in the three Papers dealing with coal shipping and dock appliances, read before the Institution at Cardiff, in July 1906, was, therefore, not supported by exhaustive trials on electrically-driven plant. If he remembered rightly he was the only speaker at the Cardiff Meeting who advocated the use of electrical energy as a motive power for dock appliances, and naturally it gave him the liveliest satisfaction to note the move in the right direction.

The authors were fortunate in being able to lay down the plant for a new dock. That was a very different matter to bringing old plant up to modern requirements. As one familiar with the arrangement of docks and harbours at home and abroad, he urged engineers to consider the question of electrifying their pumping stations if entire electrification was impossible. He advised them to endeavour to obtain power in bulk from public supply concerns, as such concerns were provided with the plant necessary for the supply of current on advantageous terms. It was his opinion that, in nine cases out of ten, it was an economic mistake for comparatively small power-users to generate their own current. In this country there were many concerns prepared to deliver converted current on the d.c. bus-bars at a cost of well under 1*d.* per unit. It was exceptional for a comparatively small power-user to be in a position to do that. That it was possible to buy power in bulk was one of the greatest advantages of electric driving over all other methods, and he deplored the fact that engineers continued to lay down small and inefficient plants.

As to the cost of water power, judging from what Mr. Tannett-Walker, Mr. Macaulay, and other speakers had told them, he thought that it would be a good thing in the future to denote the cost of water power by the letter x, where x represented an unknown quantity. Engineers would do well carefully to consider the question of distribution. In his opinion bare copper or aluminium conductors should be avoided as much as possible. He very much doubted whether the system adopted by the authors had been in use a sufficient length of time to develop the faults inherent to the system. He would like the authors to inform him if they had altered the feeding points at any time, and if so what they had done with the "slack" in the feeders. If, in this instance, they effected a saving of several thousands of pounds, could they tell him the cost of their distribution system?

From a distribution-engineer's standpoint no doubt the best system was that in which lead-covered cables were laid in a subway, with connections in lead boxes with wiped joints, from which the cables to the crane connecting-boxes were laid on the solid system in U-shaped earthenware troughs. When the network and feeders were laid on the solid system, it was his firm opinion that treated wooden troughing should not be used. Experience on several large networks led him to believe that the only satisfactory solid system was lead-covered cable, in the form of a ring, laid in earthenware troughs bedded on concrete, and filled solid with bitumen, with a line of Staffordshire blue bricks laid over the top, so as to give warning to those opening up the ground.

Hydraulic and electrical engineers had long recognized the importance of load equalization, which depended largely on the conditions on which power could be obtained in bulk. In a simple crane equipment he believed that a storage battery and automatically reversible booster was the best solution, and—in the case of an installation which had only one battery—the best place for the battery was the load centre. Local conditions often necessitated

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considerable departure from that simple rule. Much ingenuity had been shown in the design of boosters, but for crane work he thought that the machine with a single-field winding and with few adjustments was the best.

With coal-hoists he thought that the only solution of the problem of load equalization was a fly-wheel load-equalizer—the so-called Ilgner converter. In connection with the storage of energy, the authors (page 34) claimed to have arranged an entirely new combination, and he would be glad if they would give further particulars of the equipment, and a diagram. To him it appeared that their arrangement was, fundamentally, the same as that used for rolling mills and electric winding-engines. He might be mistaken, but he would much like further details.

He would be glad to know the rating of the motors used for the coal-hoists, and for each of the other machines. He expressed the opinion that makers and users paid insufficient attention to the question of rating, and, as a result, one of two things was bound to happen. Either the motors selected were too small for the work they had to do, or they were too large. If they were too small, sooner or later they would burn out. He had shown * that a time-rating for intermittent motors was radically wrong, and that the only satisfactory method of rating for an intermittent motor was the load-factor method. He hoped that engineers would give the matter their attention, and suggested that the subject was sufficiently important to mechanical engineers to justify the formation of a Research Committee.

As far as possible the speeds of cranes and capstans should be such as to require a minimum number of different sizes of motors for the operation of the several motions.† By so doing, great economies were effected, as few spare armatures, controllers, and resistances had to be stocked.

The title of the Paper led him to believe that the authors would deal with switch-gear, and he was disappointed to find that they had not done so. Much of the trouble in the past had been

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* *Electrician*, 8 Nov. 1907.

† *Ibid*, 25 Oct. 1907.

due to faulty switch-gear, and he advised engineers to specify iron-clad gear with mica insulation and renewable contacts. Magnetic blow-outs should be fitted to controllers and to circuit-breakers. He thought that resistances should be of the stamped grid type with mica insulation. When that was impossible, woven nets with asbestos and mica insulation were satisfactory substitutes. Details were of paramount importance in electrical work.

Praiseworthy features of the coal-hoists were the simplicity of the control gear and the device which prevented the operator accelerating the gear too rapidly. He had no desire to trespass too much on the authors' time, but he would like to know how the lifting gear of the coal-hoists was arranged, and also how much of the gear was balanced. He thought that an overall efficiency of 80 per cent., at about half-load, was highly creditable to the makers of the plant.

Mr. Baxter's comparative tests at the Princes Dock, Glasgow, in 1902–3, demonstrated the superiority of the electric crane over the hydraulic crane. From the Paper it was evident that other comparative tests of an exhaustive character had been made. That a mechanical engineer and an electrical engineer working in collaboration had succeeded in overcoming very great difficulties augured well for the future. He had hoped that the Rothesay Dock would be called the "All Electric" Dock to mark the commencement of the new era.

Mr. A. COLLINGWOOD wrote that he would like to refer to a point which, he believed, had been touched on by Mr. Patchell (page 44). The authors did not appear to have justified the equipment of a separate generating-station in preference to purchasing power. Every case of this sort had to be considered on its merits with due regard to local conditions, and the latter were not given in the Paper. The present works-costs of 0·89*d.* per unit were very low for a station generating only 560,000 units per annum, and spoke well for the careful design of the station, but capital charges made the total costs 2*d.* per unit. Had a

(Mr. A. Collingwood.)

three-phase supply been purchased and motor generators installed, these capital charges would have been reduced 60 per cent. and would have been about 0·44*d.* per unit. A supply at 1*d.* per unit at high-tension terminals with 84 per cent. efficiency of motor generators would cost approximately 1·63*d.* per unit at low-tension terminals, which compared with 2*d.* per unit given by the authors. Again, for a consumer purchasing 1½ million units per annum, most supply companies would be only too glad to give a supply at a price comparing favourably with 0·94*d.* per unit, even after all transforming losses and costs of motor generators had been allowed for. Should this low figure of 0·94*d.* per unit be reached when the docks were taking their full demand, it was a figure which would tend to rise slightly as the plant wore out, whereas the prices given by supply companies had throughout tended to fall as time went on.

Mr. JOHN MACAULAY, General Manager, Alexandra, Newport and South Wales Docks and Railway, Newport, Mon., wrote that they all recognized the value of such Papers as the one under discussion, whatever they might prove or disprove. The fact that a large number of technical and commercial gentlemen were always striving to attain greater efficiency and economy in the works under their control was, although the ideal conditions might yet be a long way off, an earnest of the progressive spirit which dominated their actions, and, while that spirit continued, one might rest assured that there was no ground for the pessimistic views which some held as to the decadence of this country. From the description given, the installation, both in the matter of generating plant and coal shipping appliances, etc., appeared to leave nothing to be desired from the point of view of the most modern achievements in electrical science having been brought to bear upon the problems which presented themselves, and he thought, as pioneers in this country of electrically-worked hoists, the Engineers to the Clyde Navigation Trustees, were, at any rate, to be congratulated on the courage of their convictions, notwithstanding the great dearth of experience in similarly operated plant, which was almost as great now as it had been at the time their installation was undertaken about two years ago.

The writer was also somewhat flattered that, out of the many hydraulic installations in the country, that of Newport had been chosen by the authors with which to compare the performances of their own electrically-operated coal-shipping appliances. He would like to point out, however, that when his own Paper * was written, namely, in July, 1906, for the Summer Meeting of this Institution at Cardiff, the figures published therein were not obtained by attempting to equal or better the result of some other installation, but stood by themselves as an illustration of what could be done at Newport under practically ordinary working conditions. These figures had, it appeared, acted as a spur to their friends in the North. Bearing in mind the fact that, as between two appliances the mechanical efficiency of which was, for all practical purposes, about the same, the speed of working that could be attained at a test depended largely upon the greatest average efficiency of the combined organization, which, in its turn, was dependent upon the degree of intelligence and smartness of the human units which governed the operations at the various points, he was not surprised to find that the figures he gave in 1906, so far as the speed of working the hoists was concerned, had been to some extent improved upon at the Rothesay Dock. But, as might be imagined, using in his turn the Rothesay Dock figures as the standard to be attained or surpassed in this respect, the writer had, quite recently, carried out careful tests as to the capabilities of the most modern of his hoists, namely, those which had been erected within the last four years in the South Dock Extension, and had had no difficulty in creating a new record, which the authors might, when they had had longer experience with their electrical plant, attempt to annihilate.

He put in two sets of tests, one made on the 9th February 1911 at No. 6 Hydraulic Hoist in coaling the S.S. "Don Cæsar," and the other made on the 14th February at No. 8 Hydraulic

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* Proceedings I.Mech.E., 1906, Part 3, page 435.

(Mr. John Macaulay.)

TABLE 9.

Particulars of Coaling Tests at Hydraulic Hoist No. 6 *S.D.* 9–2–11. (A. N. D. and R., Newport.)

S.S. "DON CÆSAR."

	Number of wagons dealt with.	Total time of coaling.	Equivalent number of wagons per hour.	Height of lift.	Weights.			Tons of coal per hour.	Time per cycle.	Total gallons.	Gallons per cycle.	Gallons per hour.	Gallons per ton.	Tons per gallon.	Cost per 1,000 tons shipped.	
					Gross weight.	Net weight.	Average weight of coal per wagon.								Water at 4½*d.* per 1,000 gal.	Electricity at 1*d.* per unit.
		m. s.		ft. in.	t. cwt. qr.	t. cwt. qr.	t. cwt. qr.		sec.						*s. d.*	*s. d.*
Newport actual	27·0	30 0	54	33 6	496 6 0	319 2 0	11 16 1·5	638·2	66·6	5,238	194	10,476	16·425	0·0609	—	—
Newport converted	29·5	30 0	59	27 10	542 4 0	348 13 0	11 16 1·5	697·3	60·6	4,749	161	9,498	13·62	0·0736	5 1	—
Rothesay Dock	30·0	31 37	57	27 10	416 10 2	252 14 0	8 8 1·9	479·5	63·2	25 units.	0·833 unit per cycle.	47·44 units per hour.	0·098 unit per ton.	10·1 tons per unit.	—	8 2

TABLE 10.—(Test 1.)

Details of actual Cycle of Operations.	Gross Weight of 10- and 12-ton wagons.		
	T. C. Q. 16 10 0	T. C. Q. 19 5 0	T. C. Q.
	sec.	sec.	sec.
Securing wagon on cradle and raising to a height of 33½ feet	18	20	—
Tipping loaded wagon	11	11	—
Lowering platform with empty wagon to cradle chamber	11	10	—
Lowering cradle with empty wagon to high-level viaduct	9	9	—
Uncoupling and running wagon off	6	6	—
Lowering empty cradle from high-level viaduct to ground	10	10	—
Total time per cycle	65	66	—

Mechanical Efficiency.

Total unbalanced load . . . . = 39 tons
Height lifted . . . . . = 10 feet
Time of hoisting . . . . . = 1 minute
Speed of hoisting . . . . . = 10 f.p.m.
H.p. due to load . . . . . = 26·47
Water in gallons . . . . . = 58·06
Water h.p. . . . . . . = 30·35
Efficiency = 87 per cent.

Gross load . . . . . . = 28·25 tons
Speed of hoisting . . . . = 112 f.p.m.
H.p. due to load . . . . . = 214·8
Water in gallons . . . . . = 194·5
Water h.p. . . . . . = 338·8
Efficiency = 63 per cent.

Efficiency with gross load 32 tons = 71 per cent.

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TABLE 11.

Particulars of Coaling Tests at Hydraulic Hoist No. 8, *S.D.* 14–2–11. (A. N. D. and R., Newport.)

S.S. "HOLMESIDE."

	Number of wagons dealt with.	Total time of coaling.	Equivalent number of wagons per hour.	Height of lift.	Weights.			Tons of coal per hour.	Time per cycle.	Total gallons.	Gallons per cycle.	Gallons per hour.	Gallons per ton.	Tons per gallon.	Cost per 1,000 tons shipped.	
					Gross weight.	Net weight.	Average weight of coal per wagon.								Water at 4½*d.* per 1,000 gal.	Electricity at 1*d.* per unit.
		m. s.		ft. in.	t. cwt. qr.	t. cwt. qr.	t. cwt. qr.		sec.						*s. d.*	*s. d.*
Newport actual	30·0	30 0	60	29 0	483 5 0	305 6 0	10 3 2	610·6	60·0	5,040	168	10,080	16·508	0·0605	—	—
Newport converted	30·5	30 0	61	27 10	499 7 1	315 9 2	10 3 2	630·47	58·7	4,910	161	9,820	15·564	0·0642	5 10	—
Rothesay Dock	30·0	31 37	57	27 10	416 10 2	252 14 0	8 8 1·9	479·5	63·2	25 units.	0·833 unit per cycle.	47·44 units per hour.	0·098 unit per ton.	10·1 tons per unit.	—	8 2

TABLE 12.—(Test 2.)

Details of actual Cycle of Operations.	Gross Weight of 10- and 12-ton wagons.		
	T. C. Q. 15 15 0	T. C. Q. 19 0 0	T. C. Q.
	sec.	sec.	sec.
Securing wagon on cradle and raising to a height of 29 feet	17	19	
Tipping loaded wagon	7	8	
Lowering platform with empty wagon to cradle chamber	10	10	
Lowering cradle with empty wagon to high-level viaduct	7	7	
Uncoupling and running wagon off	6	6	
Lowering empty cradle from high-level viaduct to ground	8	10	
Total time per cycle . .	55	60	

Mechanical Efficiency.

Total unbalanced load . . . . = 39 tons
Height lifted . . . . . . = 10 feet
Time of hoisting . . . . . = 1 minute
Speed of hoisting . . . . . = 10 f.p.m.
H.p. due to load . . . . . = 26·47
Water in gallons . . . . . = 58·06
Water h.p. . . . . . . = 30·35
Efficiency = 87 per cent.

Gross load . . . . = 28 tons
Speed of hoisting . . . . = 96·6 f.p.m.
H.p. due to load . . . . . = 183·7
Water in gallons . . . . . = 168·3
Water h.p. . . . . . = 293·1
Efficiency = 62 per cent.

Efficiency with gross load 32 tons = 71 per cent.

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Hoist in coaling the S.S. "Holmeside," and in Tables 9 and 11 (pages 104 and 106) he had compared the results of each of these tests with those obtained at the Rothesay Dock, as given in Table 3 (page 20). As the actual tests at Newport were made with the heights of lift of 33 feet 6 inches and 29 feet, the figures in the first line were the actual results obtained, but, in order to compare them with what was done at the Rothesay Dock, he had shown what the results were equivalent to with a height of lift corresponding to that at which the tests were carried out at the Rothesay Dock, namely, 27 feet 10 inches.

Comparing a few of the more important results in these tests, and using in every case the converted Newport figures, he found that as regards the equivalent number of wagons dealt with per hour in the first test, he improved upon Rothesay Dock figures by two wagons, and in the second test by four wagons, per hour. As a matter of fact, in the latter case, the actual test itself showed an improvement of three wagons per hour over Rothesay Dock figures, although the height of lift was 1 foot 2 inches more.

As to the quantity of coal shipped per hour, this, on similar conditions as to lift, was, to the nearest ton, 697 and 630 tons at Newport respectively, against 479 tons at Rothesay Dock, but, inasmuch as the coal shipped per hour depended entirely upon the average weight of coal per wagon, and as both hoists had been designed for dealing with wagons of a far greater carrying capacity than those which were actually in use at the times of the tests, he did not attach undue importance to this phase of the results. In times per cycle, also, it would be seen that at Newport they had easily improved upon their rival's figures, but this in his opinion, was not so much due to the means by which the hoists were mechanically operated, but, in a large measure, to the degree of human efficiency employed throughout; so that, in these respects, the assumed superiority of electric over hydraulic hoists had, for the time being at any rate, been disproved. But it was quite clear from the results of his tests, that, given wagons of the same capacity, the quantity of coal shipped per hour was not likely to be equalled by electric hoists for some time to come, and if and when this did happen, he hoped they would be able to show that they could do even better with hydraulic hoists, although, from a commercial point of view, the best results which might show an advantage of one or two wagons per hour were not of practical value.

The sheets of particulars accompanying these remarks contained Tables 10 and 12 (pages 105 and 107) similar to Table 2 (page 18) giving details of the actual cycle of operations. The figures they had obtained were on a basis of 33½ and 29 feet lifts respectively, as against 57 feet in the case of the Rothesay Dock, but, as the total time occupied per cycle had in each case been compared in the first Table, he had not thought it worth while to convert the details to corresponding lifts. At the bottom of each Table the combined efficiencies were shown, the mechanical efficiency as 87 per cent. and the commercial efficiency (if the term was permissible) as 63 per cent. in the one case and 62 per cent. in the other. The commercial efficiency with a gross load of 32 tons, which the hoists had been designed to be capable of dealing with ultimately, would be 71 per cent. Here, of course, the electrically-operated hoist had an advantage, inasmuch as the energy expended was more or less proportional to the load lifted, whereas, in hydraulic hoists the energy expended was practically constant.

He now came to the most important of the rival merits of electric versus hydraulic working, namely, to the cost of working referred to on pages 22, 23, 31 and 32 of the Paper, and would again refer to his own Tables 9 and 11 (pp. 104, 106), the last line of which gave figures in respect of Rothesay Dock taken from the authors' Table 3 (page 20), but in the last column the cost per thousand tons shipped by the electrical plant had been put at 8*s.* 2*d.* which corresponded to the lift of 27 feet 10 inches, instead of 10*s.* 11*d.* in the authors' Table 4 (page 20) in which a lift of 46 feet was assumed for the purpose of comparison. This figure of 10*s.* 11*d.* with a 46-foot lift, or 8*s.* 2*d.* with a 27-foot 10-inch lift, was, it appeared, the cost of shipping 1,000 tons of coal at 1*d.* per unit, it having been assumed that the total cost to produce the energy that would be required when the Rothesay Dock was completed

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and working at its full capacity of about one and a half million units, would be slightly under this figure.

Having regard, however, to the fact that the hoists had been working for a comparatively short time; that the time that had elapsed was an absolutely inadequate period upon which to base any sound conclusions; and, moreover, seeing that—to quote the authors—"the capital charges at present increase the above figure to approximately 2*d*. per unit," or twice the cost of 1*d*. taken in the Table with which to compare the cost of hydraulic working, it was, even if, as the authors assumed, there were no reliable records in regard to the latter, surely a case of assuming too much in favour of one's own estimates to make out a saving in favour of electrical working which had no greater justification than that obtained by adopting unreliable figures in both cases. It was not reasonable when comparing the performance of an electrically-operated plant for which the highest efficiency and economy were claimed, to take the *average* cost of working of hydraulic plant of varying degrees of efficiency and economy. Obviously, the proper thing to do, if a correct opinion was to be formed of their relative values, was to search for the most modern, effective, and economical hydraulic plant installed. Now, seeing that the authors recognized that the only hydraulic plant with which to compare the efficiency and economy of the electrically-operated plant was that at Newport, he was sorry they did not place their remarks beyond the reach of effective criticism, and, incidentally perhaps, have modified their views and expectations in regard to the comparative values of the two plants by coming to Newport and ascertaining the actual facts. If they had done this, the writer could have proved to them, as he now did by the Table of costs of hydraulic power at the Alexandra Docks for the years 1906 to 1910 inclusive (page 111), that their conclusions were fallacious.

The working cost he had shown included labour, labour maintenance, stores working, stores maintenance, sundries, fuel and fire insurance. The capital cost of the station was also given, interest being taken at 4½ per cent., depreciation on machinery at

TABLE 13.

Cost of Hydraulic Power at Alexandra Docks, Newport, Mon., for the Years 1906, 1907, 1908, 1909 *and* 1910.

						1906.	1907.	1908.	1909.	1910.
WORKING COST.						£ 2,964	£ 3,547	£ 3,181	£ 3,118	£ 3,571
CAPITAL CHARGES.	1906.	1907.	1908.	1909.	1910					
	£	£	£	£	£					
Pumping Engine House, Machinery and Accumulators	47,964	48,981	50,392	66,365	67,365	—	—	—	—	—
Interest at 4½ per cent.	—	—	—	—	—	2,158	2,204	2,268	2,986	3,031
Depreciation at 4 per cent. on Machinery	27,000	28,000	29,392	41,365	41,365	1,190	1,230	1,286	1,785	1,785
1 per cent. on Buildings	10,964	10,981	11,000	13,000	13,000					
3 per cent. on Accumulators . . .	10,000	10,000	10,000	12,000	13,000	300	300	300	360	390
TOTAL COST . .						£6,612	£7,281	£7,035	£8,249	£8,777
Gallons Pumped						340,418,798	356,045,850	395,574,501	407,647,741	468,828,891
Working Cost per thousand gallons						2·08*d.*	2·39*d.*	1·93*d.*	1·83*d.*	1·82*d.*
Total Cost per thousand gallons						4·66*d.*	4·90*d.*	4·26*d.*	4·85*d.*	4·49*d.*
Equivalent Working Cost per B.T.U.						0·32*d.*	0·367*d.*	0·296*d.*	0·281*d.*	0·28*d.*
Equivalent Total Cost per B.T.U.						0·71*d.*	0·75*d.*	0·655*d.*	0·746*d.*	0·69*d.*
Tonnage Handled, including coal and coke exported and general imports and exports						5,579,494	5,721,501	6,064,851	5,792,150	5,787,983
Average Total Cost per ton, *including* water used for locking and all other dock purposes						0·284*d.*	0·305*d.*	0·278*d.*	0·341*d.*	0·363*d.*

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4 per cent. and on buildings at 1 per cent., with the result that the following interesting figures for 1910 were obtained :—

	d.
Average working cost per thousand gallons	1·82
Average total cost per thousand gallons	4·49
Average total cost per ton of tonnage handled, including pressure water used for all purposes	0·363

There was absolutely nothing indefinite about these figures, and they might have been available to the authors. It did, therefore, appear to the writer to be a serious flaw in the value of the comparisons made to adopt the figure of 9*d.* per thousand gallons, which, it would be observed, was more than twice the total cost per thousand gallons at Newport, for the year 1910. Applying these figures to the last two columns of Tables 9 and 11 in the two statements, the cost per thousand tons shipped at Newport was found to be 5*s.* 1*d.* and 5*s.* 10*d.*, against 8*s.* 2*d.* at Rothesay Dock, or 37·7 per cent. and 28·5 per cent. less respectively, or comparing the average cost per ton shipped at the tests with a 27-foot 10-inch lift one got 0·065*d.* per ton at Newport as against 0·098*d.* per ton at Rothesay Dock—or 50 per cent. more at the latter place—and this notwithstanding the fact that the Rothesay Dock figures were based on the low total cost of electrical energy of 1*d.* per unit for which there was no apparent justification.

The figures in Table 13 (page 111), being the actual results obtained through five years' complete working, and not the less reliable results from isolated tests, were the most effective comparisons as to relative costs of working between electric and hydraulic hoists that could be obtained, but as the question might arise as to what was the result of working the Newport hydraulic cranes, the writer said that more than two years ago he had had a careful test made of a battery of hydraulic cranes working under ordinary conditions, with the result that the average cost per ton worked out to practically the same figure as the average figures given above, which were in respect of the total tonnage.

There was then the question of maintenance. Here again, he felt sure the result of two years' working was not sufficient upon which to base the average cost of the upkeep of electrical plant, and the figures obtained from such a period must be absolutely inadequate to form the basis of a proper comparison with the upkeep of a hydraulically-operated plant. It was a pity that the authors did not support their statement on page 23 by giving the result of their experience in figures, but, no doubt, this was a matter which they would now be willing to do, although, as he had already stated, the plant had been installed too recently to enable one to accept any figure as representing a fair unit cost of upkeep. With regard to the maintenance of hydraulic plant, however, he had had the figures got out for the last five years, and found the average cost of hoist maintenance had been 0·235*d*. per ton, and the average cost of hydraulic crane maintenance during the same period 0·272*d*. per ton. These figures represented the whole of the hoists and cranes at the Alexandra Docks, of which there were 17 of the former, and 43 of the latter, ranging in length of time they had been in use from two to about thirty-five years. The capacities of the cranes ranged from 30 cwt. to 6 tons, and there was a crane of 30 tons capacity.

In conclusion, there was just one more important point to which he would like to refer, and that was the question of storage of power. He had not had time to go into the question of figures minutely, but no doubt one of the great advantages of hydraulic power was that large storage could be effected by means of accumulators to enable high loads for very short periods to be negotiated without the necessary increase in engine power, which would otherwise have to be installed to meet the maximum load possible. Electric storage was, he believed, still more or less in the realms of experiment, and anything like a storage of thousands of horse-power, such as could be obtained with hydraulic power at a moderate figure, would mean a very heavy initial cost and very heavy maintenance charges if attempted electrically on anything like the same scale. There was, however, absolutely no difficulty in meeting the intermittent demand made upon a hydraulic installation with a load-factor varying from 20 or 30 per cent. to 80 or 100 per cent. for short periods either in first cost or

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maintenance. The accomplishment of this with hydraulic accumulators could be done for about £8 per h.p.-minute stored, whereas the increase of engine power to meet the same demands would cost from £20 to £25 per h.p. developed, and there was scarcely any limit to the storage capacity of hydraulic accumulators.

Mr. R. P. Morrison wrote in continuation of his remarks at the Meeting (page 73), that in getting out the cost per 1,000 gallons for hydraulic pumping plants it was necessary to include the capital charges, depreciation, and upkeep on all accumulators—not only those at the main stations but also on all "island" accumulators. He was aware that this was not the usual practice, but maintained that it was the only basis on which a fair comparison could be made between hydraulic and electric power for dock-work. In justice to the authors it was even more necessary, as they claimed to have obtained by their system the equivalent of the hydraulic accumulator for storing energy to meet peak-loads. He believed the figure of 4·49*d.* per 1,000 gallons now given by Mr. Macaulay was no exception to the above practice, and if this were so he hoped Mr. Macaulay would add the necessary information, thereby greatly increasing the value of his statistics.*

He quite agreed with the authors that high lifting-speeds were not necessary, and not desirable in most cases; the output of a tip was mainly dependent on circumstances independent of the tip itself. A very good lifting-speed was 120 feet per minute, and this was the speed of most of the tips for which Colonel Tannett-Walker gave record tipping results. On page 22, referring to the coaling tests of a Rothesay Dock electric hoist on 10th February 1909, the authors claimed that had the hoist been working to its full capacity it would have shipped at the rate of 1,140 tons of coal per hour. His experience was that although he had often tipped more than sixty wagons per hour when manipulating 20 tons

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See Mr. Macaulay's Communication (page 112).

gross trucks, he had never so far been able to deal with more than thirty-four wagons of 30 tons gross in one hour, and he had had experience with these heavy wagons at Liverpool, Goole, and Hull.

The hydraulic coal-hoist had a great advantage over an electric hoist in that it was not necessary to use wire-ropes either for lifting, tipping or balancing. Wire-ropes had a way of giving out when least expected, and were a source of much anxiety to those in charge; he was strongly opposed to their use in most cases. A very conservative estimate of the cost of wear and tear of the wire-ropes on a 30-ton hoist, having ropes for all purposes, was 3*s.* 4*d.* per 1,000 tons of coal shipped. He had personally followed the trials of belt-conveyors at Hull with very great interest, but his impressions thereby gained were very different from those expressed by Mr. Roger T. Smith (page 57).

Mr. ARTHUR RIGG wrote that he wished to contribute a few remarks on the subject of electric versus hydraulic power, with which the Paper chiefly dealt. Passing by the somewhat complicated arrangement described on page 12, noting also the type of construction (page 14), and the construction of working arrangements as used (page 15), one came to the conclusion (pages 21–22) that the condition of variable power was *impossible* with hydraulic power, although considerable improvement was effected by the use of their multiple-cylinder engine called the "Clyde" engine designed by them. Having designed and constructed hydraulic engines with variable stroke under the control of an ordinary "Watt" governor, the writer could not admit this conclusion, and as one of these engines was driving a capstan in the neighbourhood of Westminster, it might be of interest for the members to have some particulars of its construction.

This capstan engine gave a haulage of 3 tons on the rope. It was made for the South Metropolitan Gas Co. and was fixed on the south side of the river close to the Vauxhall Bridge. It had a variable stroke which was regulated by an ordinary Watt governor through a relay to limit its speed to about 300 or 400 r.p.m., a speed which enabled it to bring up the slack rope with

(Mr. Arthur Rigg.)

great rapidity. A single lever controlled the starting, regulating and variable speed, stopping or reversing, and in fact this engine did everything that could be claimed for electricity as claimed on page 35. Accepting the conclusions arrived at on this page (35), hydraulics possessed the advantage over electricity in being better able to withstand rough usage, and he thought that any comparisons between the two systems should be made between both of them at their best.

Mr. F. J. **Warden-Stevens** wrote that he had had occasion to consider various systems of coal handling and for different requirements, and he would therefore like to add a few remarks to the discussion on this important subject. In this country the desire to continue with or repeat old arrangements was without doubt a great hindrance to the adoption of improved methods, even in cases where the advantages were evident; therefore, it seemed to him, that insufficient credit had been given to the authors for having had the courage to make a new departure, and he thought the thanks of the Institution were due to them for this reason alone. Specialization rendered restraint from favour most difficult, as this discussion had shown, yet, as mechanical engineers, they should surely welcome innovations showing fair prospects of success. Steam, it might be said, had given way to hydraulic power, and rapid advances having been made in the applications of electricity, its suitability for working cranes and capstans had been proved. Now that electricity had been adopted entirely at Rothesay Dock for power purposes, including coal-hoists, hydraulic engineers must reasonably allow a fair trial to prove if electric coal-hoists and tips were not equally as advantageous as those worked by hydraulic power. At Rotterdam and Emden electric coaling-hoists and tips have been in operation successfully for some years; in the case of Emden, the control-cabin was at the top of the hoist, but the machinery was situated on the ground level adjoining, as with a colliery winding-gear. The Emden hoist has been in operation for some nine years, and was of interest, he thought, in showing that the German engineers had seen the advantage of adopting electricity for the purpose for some time, but the Rothesay Dock hoist was a considerable improvement in design, economy, and speed. He would also mention that a wagon-hoist and tip, which was operated electrically, had been in use for some three or four years at a colliery company's wharf, and this had the machinery situated on the top of the structure as in the case of the Rothesay Dock hoists.

He was pleased to note that one member had referred to the conveyor system of coal handling for docks (p. 57), which the writer considered was destined to extend rapidly on account of its advantages in the direction of continuous as against intermittent working in the case of hoists, resulting in a much improved load-factor; also because of the considerable saving in first cost and cost of working, as well as the comparatively small power-plant necessary compared with that required for hoists and tips. Further, conveyors offered advantages by reduced breakage of the coal, especially if used in conjunction with adjustable discharge-jibs or suspended lowering devices.

Regarding the position of the generating station at the Rothesay Dock, it appeared unfortunate that valuable space had been taken up so near the quay, as electricity offered advantages in economy of transmission from a distance; perhaps the authors would state the reason for the location decided upon. Concerning capstans, there could be little doubt that the free-head type with clutch and fixed rope offered great advantages from the point of view of reduced wear of rope, also on account of reduced strains on the motor and gearing.

Mr. J. MALCOLM WELLS wrote that the authors had referred to the Papers on Coal-Shipping Appliances read before this Institution at the Cardiff Meeting in 1906. In the discussion that followed, a very important question was raised by Mr. A. T. Tannett-Walker, namely, seeing that with an ordinary compound condensing engine an indicated horse-power-hour could be obtained from $1\frac{3}{4}$ lb. of coal (steam-pressure he believed at 80 lb. per square inch), was it worth while putting down more elaborate engines such as Mr.

(Mr. J. Malcolm Wells.)

Macaulay had installed at Newport, namely triple-expansion engines, steam-pressure 180 lb. per square inch, in order to save ½ lb. of coal per i.h.p. and reduce the consumption to 1¼ lb. per i.h.p. In reply, Mr. Macaulay said he thought it was well worth while, as with 1,800 i.h.p. installed a decrease of ½ lb. of coal per i.h.p. per hour would mean approximately 3,519 tons of coal at 9*s.* per ton, amounting to £1,584 per annum.

What the writer wished to point out was: that it would be impossible to effect this saving unless an annual load-factor of 1·00 was obtained for the whole capacity of the plant including reserve, which was of course out of the question. Assuming an ordinary load-factor of say 0·25 based in the usual way on maximum load on plant in use, or say a load-factor of 0·16 for the whole plant, Mr. Macaulay could only expect to save about one-sixth of his estimated saving in actual work, and even this he doubted very much whether it would be realized owing to the very intermittent nature of the load in actual work, differing so entirely from the conditions obtaining in trial runs.

The improbability of any real saving being effected was also indicated by the actual figures of an average of one month's work given by Mr. Macaulay,* where it was stated that the cost of coal at 9*s.* per ton for one month was £131, amounting to £1,562 per annum, closely approximating to Mr. Macaulay's estimated annual saving from ½ lb. of coal per i.h.p.-hour, whereas the best coal consumption obtained at the trials (page 441) was 1·37 lb. per i.h.p., a figure very considerably exceeded in actual work. The saving in initial capital cost effected by using lower steam-pressures should not be lost sight of by hydraulic engineers, although the writer did not suggest that the pressure should be as low as 80 lb. per square inch.

The AUTHORS wrote that they had read with interest the various written Communications, which, however, did not appear to call for any further lengthy reply, most of the questions raised therein having been previously covered. As stated, the intention of the Paper was to record work done rather than to explain in detail the various methods by which it had been accomplished. The new details which Mr. Macaulay had given added additional interest to the matter, and if, as they hoped, there might be an opportunity two or three years hence to deal with the complete dock equipment, including the additional coal-hoists and transporters which had been set to work since the Paper was read, Mr. Macaulay's figures might be further dealt with.

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* Proceedings I.Mech.E., 1906, Part 3, page 493.

The main points which Mr. Macaulay now brought out were: That for a hydraulic plant equal to an electric station with an output of about 3,000,000 units per annum, the cost per 1,000 gallons was not 2*d.*, as mentioned at the Cardiff Meeting, but 5*d.*, a figure which might be taken as more or less confirmed by the figures now quoted by Mr. Meik of 8·22*d.* for Swansea, this station having an output of about half that of Newport. Both these figures went to show that they were on reliable ground in basing their comparisons on 9*d.* per 1,000 gallons as the cost of the water, and further that electricity could be generated at a figure to compare favourably with this figure of 9*d.* on an output of 1½ million units per annum, and still further that it could be generated at a figure to compare favourably with Mr. Macaulay's figure of 5*d.* per 1,000 gallons with a station equal to 3,000,000 units per annum. The discussion had shown that, had figures regarding maintenance been quoted which compared favourably with hydraulics, such figures would hardly have been accepted, owing, amongst other causes, to the plant having been, as stated by Mr. Macaulay, "installed too recently." It was in anticipation of such an attitude that the authors contented themselves with stating "that the results so far showed that the cost of upkeep is not exceeded, and is not likely to exceed that required for the upkeep of plant operated by hydraulics or steam." The reason for selecting Newport for comparison was not that the results obtained at Newport appeared to be any better or any worse than those obtained at Rothesay Dock, but because they were the only tabulated figures which could be found with which to form a comparison, and were

(The Authors.)

included in a Paper read before this Institution, and from which considerable discussion of the relative merits of the two systems evolved. Notwithstanding all that had been said, they imagined that Mr. Macaulay and the authors were at one as to the relative advantages of hydraulic and electric coal-hoists.

The remarks of Mr. Roger T. Smith were interesting, the more so that he had raised the question of the shipment of coal by conveyors (page 57). Where they could be applied, belt-conveyors might be a profitable method of shipping coal, seeing that as the wagons had not to be raised to the same height as the coal the power required was considerably less, and with continuous running the size of the motors might be much reduced. The quay space required for belt-conveyor plants, however, would make their use prohibitive on the Clyde and many other ports. Two of these at 500 tons per hour would scarcely be equivalent to one of the 32-ton electric coal-hoists when working with the larger size of wagons. It would be practically impossible to adopt the gravity system at Rothesay Dock for the same reason as regards quay space, and also as the banks of the river were very low, but where they were high, as on the Tyne and Wear, the gravity system was undoubtedly the most economical that could be adopted.

In conclusion, it appeared to the authors that the objects for which the Paper was written have been attained, that is, that it has been shown that all dock work of any nature whatever could be satisfactorily and economically dealt with electrically, and that there was now no further need to apply three or four classes of power, as was being done in some of the most recent English dock equipments, namely (1) gas for heating; (2) water for coal-hoists, etc.; (3) electricity for cranes, etc.; and (4) compressed-air for various purposes.

The Institution of Mechanical Engineers.

PROCEEDINGS.

February 1911.

The Sixty-fourth Annual General Meeting was held at the Institution or Friday, 17th February 1911, at Eight o'clock p.m. The chair was taken by the Retiring President, John A. F. Aspinall, Esq., who was succeeded by Edward B. Ellington, Esq., the President elected at the Meeting.

The Minutes of the previous Meeting were read and confirmed.

The President announced that the following two Transferences had been made by the Council:—

Associate Members to Members.

Fyfe, John Walker,	London.
Tomes, William Jameson,	Jamalpur.

The following Annual Report of the Council was then read:—

ANNUAL REPORT OF THE COUNCIL

FOR THE YEAR 1910.

The Council have pleasure in presenting to the members the following Report of the progress and work of the Institution during the past year.

The deeply lamented death of His Majesty King Edward the Seventh has deprived the Institution of its most illustrious Honorary Life Member.

An Address was sent to His Majesty King George the Fifth upon His Accession; and it is very gratifying to report that His Majesty graciously consents to remain an Honorary Life Member of the Institution. [For reduced facsimile of the Address, *see* Plate 42, Proceedings 1910.]

His Majesty the King has conferred honours on the following Members of the Institution:—Sir William Mather has been appointed a Member of the Privy Council, and Engineer Vice-Admiral Henry J. Oram, C.B., has been made a Knight Commander of the Order of the Bath.

The changes which have taken place in the roll during 1910 are shown in the following tabulated statement:—

	Hon. M.	M.	A.M.	A.	G.	Totals.	
Totals at 31st December 1909	7	2,503	2,304	62	707		5,583
Elected	—	51	255	1	111		
Reinstated	—	1	1	—	1		
Transferred	—	44	—	—	—		
Total additions during 1910	—	96	256	1	112	465	
Deceased	1	37	7	—	—		
Resigned	—	29	29	2	16		
Erased	—	12	60	—	19		
Graduates elected Associate Members	—	—	—	—	57		
Graduates retired under By-law 3.	—	—	—	—	30		
Elections voided	—	—	1	—	4		
Transferred	—	—	44	—	—		
Total deductions during 1910	1	78	141	2	126	348	117
Totals at 31st December 1910	6	2,521	2,419	61	693		5,700

The following Deceases of members of the Institution were reported during the year: the date of election is added in each case:—

1872. Alliott, James B.
1884. Almond, Harry J.
1891. Anderson, William
1900. Atkinson, Frederick A.
1887. Barningham, James
1878. Belsham, Maurice
1901. Borham, William E.
1904. Brixey, Charles E. W. (*A.M.*)
1888. Brown, Harold (*A.*)
1887. Caiger, Emery J.
1900. Calastremé, J. Carlos
1904. Carter, Ernest (*A.M.*)
1899. Deas, James
1886. Dixon, Robert
1865. Douglas, Charles P.
1904. Fraser, Harry J.
1895. Grant, Thomas M.
1878. Greenwood, Arthur
1879. Harris, H. Graham
1885. Harrison, Frederick H.
1887. Hind, Enoch (*A.*)
1900. Hodgson, William
1890. Hopper, Allan
1880. Hornsby, James
1891. Hoy, Henry A.
1900. Hughes, Thomas W. R.
1895. Isaac, Robert
1904. Johnson, Edward (*A.M.*)
1870. Layborn, Daniel
1862. Lee, J. C. Frank
1909. Little, C. Hardy (*A.M.*)
1900. Lobb, Christopher

1886. MacLean, Alexander S.
1906. Macmillan, Hugh
1862. Mappin, Sir Frederick T., Bart.
1881. Martin, Edward P.
1906. May, Thomas A. P. (*A.M.*)
1899. Molloy, Harry J. (*Deceased* 1909)
1903. Naylor, John H. (*A.M.*)
1874. Paget, Berkeley (*A.*)
1900. Parkinson, Joseph
1877. Pigot, Thomas F.
1883. Pillow, Edward
1886. Pollock, James
1864. Potts, Benjamin L. F.
1902. Reeves, Wilfred
1885. Rogers, Henry J.
1908. Rolls, The Hon. C. S. (*A.M.*)
1874. Sampson, J. Lyons
1877. Spencer, John
1903. Storey, Percival
1898. Thorneley, William
1903. Tweedie, Kenneth D. (*A.M.*)
1856. Waddington, John
1908. Walter, D'Arcy J. (*A.M.*)
1900. Whale, George
1883. Williams, Sir E. Leader
1898. Winn, C. Reginald
1872. Wise, Sir W. Lloyd
1878. Wolfe, John E.

Of these, Mr. Greenwood was a Member of Council from 1908; Mr. Graham Harris was elected a Member of Council in 1898 and a Vice-President in 1909; Mr. Martin was elected a Member of Council in 1886, a Vice-President in 1894, and President in 1905–06; and Mr. Whale was a Member of Council from 1907.

The Accounts for the year ended 31st December 1910 are now submitted (*see* pages 134 to 139), having been duly certified by Mr. Robert A. McLean, F.C.A., the Auditor appointed by the members at the last Annual General Meeting.

The total revenue for the year 1910 was £15,624 19*s.* 2*d.*, while the expenditure was £12,734 9*s.*, leaving a balance of revenue over expenditure of £2,369 10*s.* 2*d.*, exclusive of Entrance Fees £417 and Life Compositions £104 carried direct to Capital Account. The financial position of the Institution at the end of the year is shown by the balance sheet. The total investments and other assets amount to £92,302 2*s.* 10*d.*, and, deducting therefrom the £20,000 of debentures and the total remaining liabilities, including a temporary loan of £5,000 towards the cost of purchasing the Storey's Gate Tavern, the capital of the Institution amounts to £57,004 7*s.* 9*d.*, excluding the sum set aside for the Leasehold and Debenture Redemption Fund. The certificates of the securities have been duly audited by the Finance Committee and the Auditor.

Early in the year a donation was received from Mr. Herbert A. Humphrey for engineering charities, to be expended at the discretion of the Council. The Council trust this donation may prove the precursor of many others, and that in time an adequate Benevolent Fund may be established.

Progress has been made with the plans for the extension of the Institution House. Four Architects have been invited to submit competitive designs which will shortly be submitted for adjudication. The members will, as soon as possible, be fully informed of the proposals of the Council.

The First Award in connection with the Bryan Donkin Fund for assisting original research, was announced in February (*see* Proceedings 1910, page 380), as follows: £10 to Mr. William Mason, *Associate Member*, for continuing his "Research on Combined Stress," and £10 to Professor C. A. M. Smith, *Associate Member*, for his Investigation "to obtain Data concerning the Laws of Elastic Failure of Ductile and Brittle Materials." The Second Award, of the value of about £34, will be made in February 1913, in response to applications for grants in aid of original research in Mechanical Engineering.

The Second Award of the Water Arbitration Prize, the conditions of which were issued to members on 1st July 1909 and were reprinted in the last Annual Report, has been made to Mr. William Rankine Eckart, *Associate Member*, for his Paper on "The Application of the Pitot Tube to the Testing of Impulse Water-Wheels," which was read and discussed at the General Meeting on 7th January 1910. This Prize, of the value of about £31, is offered biennially, and the Regulations for the Third Award in February 1913 are appended (*see* page 140).

The First Award of the Starley Premium, for the best original Paper dealing with the Development of Road Locomotion published in the Proceedings of the Institution during the previous three years, has been made to Mr. Lucien Alphonse Legros, *Member*, for his Paper on "The Development of Road Locomotion in Recent Years," which was read and discussed at the General Meeting on 18th November 1910. The Second Award, of a value of about £45, will be made in February 1914, and the Regulations of the Fund are appended (*see* page 141).

The work of the Alloys Research Committee has been continued at the National Physical Laboratory, and it is expected that the Tenth Report will be presented for Discussion during the current year. This Report will deal with the binary system of alloys of Aluminium-Zinc, together with some preliminary results obtained in a ternary system of Aluminium-Zinc-Copper, the quantity of Copper being limited in amount. The Committee, under the Chairmanship of Sir William H. White, K.C.B., report with regret the decease of Mr. J. D. Bonner, who, although not a member of the Institution, served for five years as a Member of the Committee.

The work of the Gas-Engine Research Committee, under the Chairmanship of Sir Alexander B. W. Kennedy, has been continued at the University of Birmingham, and Professor F. W. Burstall is preparing a Report dealing with a new series of tests on the experimental engine at the University, varying only the ratio of air to gas; dealing also with the composition of the charge during expansion. This Report will be presented to the members for Discussion at an early Meeting.

During the year Professor H. C. H. Carpenter concluded his Research, referred to in the Annual Report for 1907, upon "The Production of Castings to withstand High Pressures"; and a Paper thereon by Professor Carpenter and Mr. C. A. Edwards was presented for Discussion at the December Meeting.

Of the remaining Researches in the hands of special Committees, that on the Value of the Steam-Jacket is in abeyance at present, while that on the Friction of various Gears is awaiting the publication of the results of some experiments in the United States.

It has been decided not to undertake experiments on "Heat Transmission" at present.

Other subjects suggested by members for Research have had attention. It is hoped that the results of an investigation dealing with "The Action of Steam passing through Nozzles and Steam Turbines," also a Paper upon "Refrigeration," will be ready for Discussion in 1911; and the question of investigating "The Contraction of Crucible Cast-Steel in Hardening" is under consideration.

The Calcutta and District Section of the Institution continued its Meetings during the year. Advance copies of the English Papers have been sent to India for their use, and the following Local Papers have been read:—

The Modern Equipment of Coal Mines; by Mr. W. C. Mountain (*printed*).
Modern Printing Machinery; by Mr. H. E. Watson.
Notes on the Tallah Raised Reservoir, Corporation of Calcutta; by Mr. W. B. MacCabe and Mr. A. Peirce (*printed*).
Notes on the Methods of Construction and Erection of the Elevated Reservoir at Tallah; by Mr. J. F. Thompson (*printed*).

A visit was made to the Tallah Elevated Reservoir of the Corporation of Calcutta.

A grant of £75 has been paid from the Institution funds towards their expenses; and the Council have sanctioned an alteration in their Rules (*see* Proceedings 1910, page 360), increasing the Annual Subscription from Rs.5 to Rs.10.

The Council have had under consideration the proposals of the Marine Department of the Board of Trade as to alterations in the qualifications for Engineers in the Mercantile Marine; and have communicated to the Board their general concurrence with the views expressed thereon by the Institution of Naval Architects and by the Institute of Marine Engineers.

The Institution during the year has been represented on the following organizations:—

Universities of Bristol, Liverpool, and Sheffield.
Imperial College of Science and Technology.
National Physical Laboratory.
Engineering Standards Committee.
School of Metalliferous Mining (Cornwall).
Central Committee for Road Statistics.

Applications have been granted from time to time for the following kindred Societies to hold Meetings in the Institution House:—

Incorporated Institution of Automobile Engineers.
Institution of Mining and Metallurgy.
Institute of Metals.
Institution of Gas Engineers.
Institution of Heating and Ventilating Engineers

At the Düsseldorf quinquennial Meeting in June of the International Congress of Mining, Metallurgy, Applied Mechanics and Practical Geology, the Institution joined with five kindred Societies in an invitation to the Congress to hold its next Meeting in London in 1915. This invitation has been accepted.

The Council desire to thank those members and others who have made presentations to the Library. A complete list of additions will be found on pages 142–160. 491 books were loaned to members, and 108 searches for special information were made by the staff on behalf of members. A card-catalogue of the Library, both by author and subject, is being prepared, as a step towards making the books and pamphlets more accessible to members.

The acceptance of the invitation, sent to the American Society of Mechanical Engineers, to hold a Joint Meeting in England, was followed by an attendance of about 250 Americans with ladies at the Annual Summer Meeting, held in Birmingham and London, 25th–31st July. A Reception Committee, formed by the members residing in and around Birmingham, and other influential gentlemen, was presided over by the Right Hon. the Lord Mayor of Birmingham, Alderman W. H. Bowater, while Mr. Fred M. Lea and Mr. Howard Heaton, acted as Honorary Local Secretaries. The Council desire to express their obligation to this Reception Committee for the arrangements made by them for the entertainment of the visitors in Birmingham. The liberality of the members who responded to an invitation to raise a fund for the special entertainment of the American visitors in London enabled the Council suitably to fulfil their obligations as hosts with only a moderate charge on the funds of the Institution. Visits were made to various works and places of historic interest in the Midlands, Windsor, and in London, where the Dinner and Annual Conversazione were also held. The attendance at the Meeting included 428 members, 70 visitors, and 233 ladies, in addition to the American visitors. The Joint Meeting was an entire success and the source of much satisfaction to all concerned. The Council have placed on record their appreciation of the value of the services of the Secretary and his Staff during the Meeting.

Monthly Meetings were held throughout the year, with the exception of June, August, and September. These Meetings were occupied with the reading and discussion of the following Papers :—

The Application of the Pitot Tube to the Testing of Impulse Water-Wheels; by Mr. W. R. Eckart, Jun., *Associate Member.*

An Account of a Visit to the Power Plant of the Ontario Power Co. at Niagara Falls; by Mr. C. W. Jordan, *Associate Member.*

Ninth Report to the Alloys Research Committee: On the Properties of some Alloys of Copper, Aluminium, and Manganese (with an Appendix on the Corrosion of Alloys of Copper and Aluminium when exposed to the Sea); by Dr. W. Rosenhain and Mr. F. C. A. H. Lantsberry.

Compounding and Superheating in Horwich Locomotives; by Mr. George Hughes, *Member.*

A Research on the Hardening of Carbon and Low-Tungsten Tool-Steels; by Mr. Shipley N. Brayshaw, *Member.*

Comparison of the Tensile, Impact-Tensile, and Repeated-Bending Methods of Testing Steel; by Mr. Bertram Blount, Mr. W. G. Kirkaldy, *Member, and Captain* H. Riall Sankey, R.E. (ret.), *Member of Council.*

English Running-Shed Practice; by Mr. Cecil W. Paget, *Member.*

Handling Locomotives at Terminals; by Mr. Frederic M. Whyte, Vice-President Am.Soc.M.E.

Engine-House Practice; by Mr. F. H. Clark, M.Am.Soc.M.E.

American Locomotive Terminals; by Mr. William Forsyth, M.Am.Soc.M.E.

Handling Engines; by Mr. H. H. Vaughan, *Member* and M.Am.Soc.M.E.

High-Speed Tools and Machines to fit them; by Mr. H. I. Brackenbury, *Member.*

Rapid Production in Machine Work: Abstract of Data collected by the American Society of Mechanical Engineers; by Mr. John Calder, M.Am.Soc.M.E.

Data on Manufacturing Methods with Machine-Tools; by Mr. Luther D Burlingame, M.Am.Soc.M.E.

Development of High-Speed Drilling-Machines; by Mr. L. P. Alford, M.Am.Soc.M.E.

Tooth Gearing; by Mr. J. D. Steven, *Associate Member.*

Interchangeable Involute Gearing; by Mr. Wilfred Lewis, M.Am.Soc.M.E.

Electrification of Suburban Railways; by Mr. F. W. Carter.

Cost of Electrically-Propelled Suburban Trains; by Mr. H. M. Hobart.

The Electrification of Railways; by Mr. George Westinghouse, President Am.Soc.M.E.

Economics of Railway Electrification; by Mr. William Bancroft Potter, M.Am.Soc.M.E.

The Electrification of Trunk Lines; by Mr. R. L. Pomeroy, M.Am.Soc.M.E.

The Standardization of Locomotives in India, 1910; by Mr. Cyril Hitchcock, *Member.*

The Development of Road Locomotion in Recent Years; by Mr. L. A. Legros, *Member.*

The Production of Castings to withstand High Pressures; by Professor H. C. H. Carpenter and Mr. C. A. Edwards.

The Constitution of Troostite and the Tempering of Steel: by Mr. Andrew McCance.

The Graduates held monthly Meetings during the Session 1909–10. Three Visits were made to works in London and one in Guildford. The average attendance of Graduates was 33 at the Meetings and 24 at the Visits. The following Papers by Graduates were read and discussed:—

Invention and Industrial Progress, with a Treatise on the British Patent System; by Mr. J. E. S. Lockwood.

The Commercial Testing of Railway Materials; by Mr. T. H. Sanders.

Planning and Equipment of Turbo Generating Stations; by Mr. Thomas Walmsley.

Artesian Water Supplies; by Mr. A. D. Salway.
Locomotive Valve Motions; by Mr. G. V. V. Hutchinson.
Mechanical Flight; by Mr. A. B. E. Cheeseman.
Some Notes on Materials under Combined Stresses; by Mr. E. W. Moss.

Prizes for the best Papers have been awarded by the Council to Mr. Moss and Mr. Sanders.

At the Graduates' February Meeting, Mr. F. Leigh Martineau delivered an Illustrated Lecture on "Petrol Motors."

Graduates residing beyond the reach of the London Meetings have welcomed invitations to attend local Meetings and Debates, extended to them by the Engineering Societies of the Universities of Birmingham, Bristol, Glasgow, Liverpool, and Manchester, of the University College of South Wales and Monmouthshire, and of Armstrong College, Newcastle-upon-Tyne. The Council gratefully acknowledge this continuation of the invitations of previous years.

In order to direct attention to the advantages enjoyed by Graduates, the Rules connected with the Graduates' Association and their Annual Report for the Session 1909–10, were sent to the members.

* * *

The result of the Ballot for the election of President, two Vice-Presidents, and seven Members of Council, to fill vacancies caused by retirement, will be announced at the Annual General Meeting.

ACCOUNT OF REVENUE AND EXPENDITURE

AND

BALANCE SHEET FOR 1910.

Dr. ACCOUNT OF REVENUE AND EXPENDITURE

Expenditure.

	£	s.	d.	£	s.	d.
To Expenses of Maintenance and Management—						
Salaries and Wages	3,473	7	0			
Postages, Telegrams, and Telephone	761	16	9			
Heating, Lighting, and Power	101	18	10			
Fittings and Repairs	65	0	10			
Housekeeping	148	9	10			
Incidental Expenses	70	19	4			
				4,621	12	7
,, Printing, Stationery, and Binding—						
Printing and Engraving Proceedings	2,253	5	0			
Stationery and General Printing	771	14	7			
Binding	29	12	5			
				3,054	12	0
,, Rent, Rates, Taxes, &c.—						
Ground Rent (Institution)	875	17	2			
Do. No. 5 Princes Street	135	0	0			
Do. Storey's Gate Tavern	94	3	5			
Rates and Taxes	847	17	8			
Insurance	37	12	9			
				1,990	11	0
,, Meeting Expenses—						
Printing	606	9	3			
Travelling and Incidental Expenses	256	13	2			
Reporting	76	9	11			
				939	12	4
,, Conversazione and other special expenses				488	3	9
,, Dinner Expenses				75	5	2
,, Calcutta and District Section				75	0	0
,, Graduates' Prizes				10	1	9
,, Books purchased and Library expenses				96	17	3
,, Law Charges				1	14	6
,, Expenses in connection with Research Committees				314	18	6
,, Interest on Bank Loan				209	19	4
,, Depreciation on Furniture and Fittings				56	0	10
,, Debenture Interest				800	0	0
Total Expenditure				12,734	9	0
,, Entrance Fees, carried to Capital Account (*per contra*)				417	0	0
,, Life Compositions, carried to Capital Account (*per contra*)				104	0	0
,, Balance, being excess of Revenue over Expenditure (exclusive of value of Subscriptions in arrear), carried to Balance Sheet				2,369	10	2
				£15,624	19	2

FOR THE YEAR ENDED 31st DECEMBER 1910. *Cr.*

Revenue.

	£	s.	d.	£	s.	d.
By Subscriptions for 1910				12,916	0	0
„ Subscriptions in arrear, paid in 1910				805	10	0
„ Entrance Fees for 1910				417	0	0
„ Life Compositions				104	0	0
„ Rent of Upper Floor of Institution Building	428	2	6			
Do. Storey's Gate Tavern	565	6	2			
				993	8	8
„ Interest, &c. (exclusive of Trust Funds)—						
From Investments and Deposits at Bank	212	19	2			
Income Tax refunded	11	16	1			
				224	15	3
„ Reports of Proceedings—						
Extra Copies sold				164	0	3
„ Debenture Transfer Fees				0	5	0
				£15,624	19	2

Dr.

BALANCE SHEET

	£	s.	d.	£	s.	d.
To Debentures—						
250 of £100 each at 4%, redeemable in 1917, or at par at any date after 1st Jan. 1908, on six months' notice to holder	25,000	0	0			
Less 50 Debentures redeemed during 1908 and 1909	5,000	0	0	20,000	0	0
„ Sundry Creditors—						
Loan from Union of London and Smiths Bank (The Bankers hold as security against this Loan the Railway Debenture Stocks specified on opposite page.)	5,000	0	0			
Accounts owing at 31st Dec. 1910	1,766	12	5			
Unclaimed Debenture Interest (coupons not presented)	11	8	5	6,778	0	10
„ Subscriptions paid in advance				167	10	0
„ Donation for Engineering Charities (*balance*)				25	0	0
„ Trust Funds (see pages 138–9), *per contra*—						
Willans Premium Fund	170	0	4			
Water Arbitration Prize Fund	538	15	11			
Bryan Donkin Fund	367	6	3			
Starley Premium Fund	477	16	2	1,553	18	8
„ Sinking Fund set aside for Redemption of Debentures and Institution's Leasehold Property				6,773	5	7
„ Balance, being Capital of the Institution, exclusive of the Sinking Fund:—						
Balance at 31st Dec. 1909	54,113	17	7			
Add—						
Excess of Revenue over Expenditure for the year ended 31st Dec. 1910 .	2,369	10	2			
Amount received from Entrance Fees during 1910	417	0	0			
Amount received from Life Compositions during 1910	104	0	0	57,004	7	9
				£92,302	2	10

Signed by the following Members of the Finance Committee:—

W. H. MAW.
H. F. DONALDSON.

E. B. ELLINGTON (Chairman).
MARK ROBINSON.

AT 31st DECEMBER 1910. *Cr.*

	£	s.	d.	£	s.	d.
By Cash (exclusive of Trust Funds)—						
In Union of London and Smiths Bank—						
On Current Account	368	12	4			
,, Sinking Fund Account.	167	18	10			
	536	11	2			
In the Secretary's hands	74	4	2	610	15	4
,, Amount in Union of London and Smiths Bank to meet unclaimed Debenture Interest (*coupons not presented*) . .				11	8	5
,, Investments (*of which £6,773 5s. 7d. has been set aside for Redemption of Debentures and the Institution's Leasehold Property*) . . . . *Cost*				14,764	16	7
L. and N. W. Ry. 3% *Debenture Stock.*	5,408	0	0			
Midland Ry. 2½% *Debenture Stock.*	5,080	12	0			
2½% *Consols.*	2,709	3	4			
Metropolitan Water (*B*) 3% *Stock.*	2,781	10	8			
London County 3½% *Consolidated Stock.*	1,000	0	0			
L. & S. W. Ry. 3% *Consolidated Deb. Stock.*	674	0	0			
The Market Value of these investments at 31*st Dec.* 1910 *was about* £14,244.						
,, Subscriptions in arrear, *not valued.*						
,, Furniture and Fittings (*less depreciation*)				1,064	16	6
,, Books in Library, Drawings, Engravings, Models, Specimens, and Sculpture (*estimate of* 1893)				1,340	0	0
,, Proceedings—stock of back numbers, *not valued.*						
,, Institution House . . . . *Cost*	60,270	2	10			
,, Princes Street Extension	12,686	4	6	72,956	7	4
,, Investments and Cash in Bank on account of Trust Funds (see pages 138–9), *per contra*—						
Willans Premium Fund	170	0	4			
Water Arbitration Prize Fund	538	15	11			
Bryan Donkin Fund	367	6	3			
Starley Premium Fund	477	16	2	1,553	18	8
				£92,302	2	10

I have examined the above Balance Sheet and report that I have obtained all the information and explanations I have required. In my opinion such Balance Sheet is properly drawn up so as to exhibit a true and correct view of the state of the Institution's affairs according to the best of the information and explanations given to me and as shown by the Books of the Institution.

ROBERT A. McLEAN, F.C.A.,
Auditor,
1 Queen Victoria Street, London, E.C.

17*th January* 1911.

WILLANS PREMIUM FUND.

(Under a Joint Trust with the Institution of Electrical Engineers.)

Investment £159 8*s.* 5*d.* of India 3% Stock . . . . cost £165 5*s.* 0*d.*

Dr.	£	*s.*	*d.*	*Cr.*	£	*s.*	*d.*
To Institution of Electrical Engineers	14	6	0	By Interest, 1907 . . .	4	15	4
,, Balance, held in trust .	4	15	4	,, Do. 1908 . . .	4	15	4
				,, Do. 1909 . . .	4	15	4
				,, Do. 1910 . . .	4	15	4
				(*No Income Tax deducted.*)			
	£19	1	4		£19	1	4

See Balance Sheet.

(Declaration of Trust, *see* Proceedings 1907, page 23.)

WATER ARBITRATION PRIZE FUND.

Investment £523 10s. 2*d.* of Metropolitan Water (B) 3% Stock cost £500 0 0

Dr.	£	*s.*	*d.*	*Cr.*	£	*s.*	*d.*
To Balance	38	15	11	By Interest, 1908 . . .	7	9	2
				,, Do. 1909 . . .	14	17	3
				,, Income Tax refunded, 1909	0	15	8
				,, Interest, 1910 . . .	14	15	10
				,, Income Tax refunded, 1910	0	18	0
	£38	15	11		£38	15	11

See Balance Sheet.

(Regulations for third Award, *see* page 140.)

BRYAN DONKIN FUND.

Investment £349 15*s.* 8*d.* of London County 3½% Consolidated Stock
cost £360 6*s.* 6*d.*

Dr.	£	*s.*	*d.*	*Cr.*	£	*s.*	*d.*
To Award to Mr. W. Mason	10	0	0	By Interest, 1908	2	18	1
,, Award to Prof. C. A. M. Smith	10	0	0	,, Do. 1909	11	11	4
,, Balance	6	19	9	,, Income Tax refunded, 1909	0	6	2
				,, Interest, 1910	11	10	4
				,, Income Tax refunded, 1910	0	13	10
	£26	19	9		£26	19	9

See Balance Sheet.

(Regulations, *see* Proceedings 1909, page 228.)

STARLEY PREMIUM FUND.

Investment £435 8*s.* 5*d.* of London County 3½% Consolidated Stock
cost £440 7*s.* 6*d.*

Dr.	£	*s.*	*d.*	*Cr.*	£	*s.*	*d.*
To Balance	37	8	8	By Interest, 1908	7	4	10
				,, Do. 1909	14	8	6
				,, Income Tax refunded, 1909	0	11	3
				,, Interest, 1910	14	7	4
				,, Income Tax refunded, 1910	0	16	9
	£37	8	8		£37	8	8

See Balance Sheet.

(Regulations, *see* page 141.)

WATER ARBITRATION PRIZE.

REGULATIONS FOR THE THIRD AWARD TO BE MADE IN FEBRUARY 1913.

(1.) The Award will be made for the best original Paper dealing with NEW INVESTIGATIONS OF HYDRAULICS, OR RECENT DEVELOPMENTS IN THE APPLICATION OF WATER POWER, accepted by the Council for publication with or without discussion in the Institution Proceedings of 1911 and 1912, provided that the Paper be of sufficient merit in the judgment of the Council.

(2.) Papers should be sent in as soon as possible, but not later than 1st September 1912.

(3.) Papers should be illustrated by scale drawings, but may be accompanied by photographs, lantern-slides, and specimens.

(4.) Any Paper not accepted for printing in the Proceedings will be returned to the author.

(5.) The Prize will have the value of about £30, and will be accompanied by a Certificate bearing the seal of the Institution.

WILLANS PREMIUM.

The next Award will be made in February 1913 for the best Paper, published in the Proceedings 1907–12, inclusive, dealing with such a general subject as the utilization or transformation of energy, treated especially from the point of view of efficiency or economy. (For Declaration of Trust, *see* Proceedings 1907, page 23.)

STARLEY PREMIUM FUND.

Regulations.

Second Award, February 1914.

1. The name of the Fund shall be the Starley Premium Fund.

2. The amount of the Fund (about £440) shall be invested in the name of the Institution of Mechanical Engineers in a trustee security, with power to vary.

3. The income derived from the Fund, after payment of any expenses incidental to the administration of the Fund, shall be presented triennially in and after February 1911 for the best original Paper dealing with "THE DEVELOPMENT OF ROAD LOCOMOTION" published in the Proceedings of the Institution of Mechanical Engineers during the previous three years: it being understood that the premium shall not be awarded unless a Paper of sufficient merit in the judgment of the Council shall have been so published since the preceding Award.

4. In the event of no Award at the end of any triennial period, the premium available for that Award shall be added to the capital of the Fund, unless during the ensuing triennial period two Papers of sufficient merit and dealing with "The Development of Road Locomotion" be communicated, in which event the Council may, if they think fit, present two premiums.

5. The premium shall be awarded in any form which the Council may from time to time determine.

LIST OF ADDITIONS TO THE LIBRARY.

BOOKS, *see p.* 142.
OFFICIAL PUBLICATIONS, *see p.* 145.
PAMPHLETS, *see p.* 147.
DIRECTORIES, *ANNUALS*, *&c.*, *see p.* 151.
CALENDARS and COLLEGE REPORTS, *see p.* 151.
PHOTOGRAPHS, *see p.* 153.
PUBLICATIONS OF SOCIETIES, *&c.*, *see p.* 153.
PERIODICALS, *see p.* 158.

BOOKS (*in order received*).

Valuation for Rating (Part I), by Joseph Greaves.

The Gas, Petrol, and Oil Engine (Vol. I, new ed.), by Dugald Clerk, F.R.S. ; from the author.

Technical Dictionary in six languages: Vol. VI, Railway Rolling Stock; Vol. VII, Hoisting and Conveying Machinery; Vol. VIII, Reinforced Concrete in Sub- and Superstructure; Vol. IX, Machine Tools—Metal Working—Wood Working; from the publishers.

Practical Steam and Hot Water Heating and Ventilation, by A. G. King.

A Practical Treatise on Bridge Construction (4th ed.), by Professor T. C. Fidler.

The Manufacture of Cane Sugar, by Llewellyn Jones and F. I. Scard.

Governors and Governing Mechanism (2nd ed.), by H. R. Hall.

The Encyclopædia of Practical Engineering and Allied Trades (10 vols.), edited by J. G. Horner.

Applied Mechanics (new ed.), by Professor John Perry, D.Sc., LL.D., F.R.S.

Gas Engine Theory and Design, by A. C. Mehrtens.

A Practical Manual on Sea Water Distillation, by Frank Normandy.

Commercial Peat: its uses and possibilities, by F. T. Gissing.

The First Principles of Railway Signalling, by C. B. Byles; also duplicate from Mr. J. A. Kay.

Modern Practice in Mining: Vol. I, Coal; Vol. II, The Sinking of Shafts; by R. A. S. Redmayne.

Modern Coking Practice, by T. H. Byrom and J. E. Christopher.

Hydraulic Mining, by C. C. Longridge.

Mechanical Railway Signalling, by H. R. Wilson.

First Principles of Mechanical Engineering, by John Imray and C. H. W. Biggs; Elements of Natural Philosophy, by John Leslie; A History of the Theory of Elasticity and of the Strength of Materials: Vol. I, 1639–1850, by Isaac Todhunter and Karl Pearson; Vergleichende Versuche an Kältemaschinen, by Professor M. Schröter; from Mr. Henry Adams.

On the Art of Cutting Metals, by F. W. Taylor.

Petroleum Mining and Oil-Field Development, by A. B. Thompson; from the author.

Gross-Gasmaschinen, by Dr. A. Riedler: from Mr. D. A. Louis.

Report on the Atmospheric Railway System, by Robert Stephenson; The Engineer and Machinist's Drawing Book, by Le Blanc and M. Armengaud from Mrs. Bache.

Railway Carriages and Wagons: their Design and Construction (Part I), by Sidney Stone.

Glass Manufacture, by Walter Rosenhain.

Principles and Practice of Harbour Engineering, by Brysson Cunningham.

Fuel and Refractory Materials (2nd ed.), by Professor A. H. Sexton.

Vehicles of the Air, by Victor Lougheed.

The Design and Construction of Internal-Combustion Engines, by Hugo Güldner (translated by Professor H. Diederichs).

War-ships (4th ed.) by E. L. Attwood.

Metallography applied to Siderurgic Products, by Humbert Savoia (translated by R. G. Corbet); Practical Hints to Young Engineers employed on Indian Railways, by A. W. C. Addis; The Depreciation of Factories (4th ed.), by Ewing Matheson; Workshop Receipts (Vols. I–III, new ed.); from the publishers.

The Royal Society, by Sir William Huggins, K.C.B., O.M.; from the author.

Principles and Practice of Ironfounding, by E. L. Rhead; from Mr. W. H. Fowler.

Engineering Workshop Machines and Processes, by F. zur Nedden (translated by J. A. Davenport, M.Sc., with introduction by Sir Alexander B. W. Kennedy, LL.D., F.R.S.); from the publishers.

The Car Builders' Dictionary, compiled by F. E. Lister.

The Life of William Thomson, Baron Kelvin of Largs (2 vols.), by S. P. Thompson.

Principles and Practice of Dock Engineering (2nd. ed.), by Brysson Cunningham.

The Public School Geometry, by F. J. W. Whipple; from the publishers.

Electric Power Plants, by T. E. Murray; from the author.

The Art of Aviation, by R. W. A. Brewer; from the author.

Transactions of the Institution of Civil Engineers, Vol. I, 1836; from Mr. J. S. Warner.

International Language and Science; from the publishers.

A Text-book of Paper-making (3rd ed.), by C. F. Cross and E. J. Bevan.

Metallography, by C. H. Desch, D.Sc., Ph.D.

Practice and Theory of the Injector (3rd ed.), by S. L. Kneass.

Bridges, Structural Steel Work, and Mechanical Engineering Productions, by Sir William Arrol and Co.; from the authors.

The Testing of Materials of Construction (3rd ed.), by Professor W. Cawthorne Unwin, LL.D., F.R.S.; from the author.

Souvenir of the Continental Tour of Students of the Institution of Civil Engineers, 16–26 July 1909; from the editors.

Buildings and Structures of American Railroads, by W. G. Berg; A Treatise on Wooden Trestle Bridges, by W. C. Foster; from Mr. W. J. Weightman.

Walker's Loose Leaf Pocket Book for Engineers, by N. R. Corke; from the author.

Hütte: Taschenbuch für Eisenhüttenleute; from the publishers.

Hydraulic Elevators: their Design, Construction, Operation, Care and Management, by William Baxter, Jun.

Experimental Investigations on the Power Required to Drive Rolling Mills, by J. Puppe.

La Résistance de l'Air, by G. Eiffel; from the author.

General Foundry Practice, by William Roxburgh; from the publishers.

The Construction and Working of Internal Combustion Engines, by R. E. Mathot (translated by W. A. Tookey); from the publishers.

Sewerage and Sewage Disposal in the Metropolitan District of New York and New Jersey: Report of the Metropolitan Sewerage Commission of New York, 1910; from the Commission.

Design of Marine Multitubular Boilers, by J. D. McKnight and A. W. Brown; from Mr. Alfred W. Brown.

The Gas Turbine, by H. H. Suplee; from the author.

A Text-Book of Applied Mechanics and Mechanical Engineering (7th ed.), Vol. I, Applied Mechanics (8th ed.); Vol. II, Strength of Materials; Vol. III, Theory of Structures; Vol. IV, Hydraulics, Hydraulic and Refrigerating Machinery, with Pneumatic Tools; Vol. V, Theory of Machines and Practical Mechanisms; by Professor Andrew Jamieson.

A Text-Book of Physics (4th ed.), by Professor William Watson, F.R.S.

American Machinist Gear Book, by C. H. Logue.

Electric Circuit Problems in Mines and Factories, by E. H. Crapper; from the publishers.

Bibliography of the Cotton Manufacture, by C. J. H. Woodbury; from the author.

Calculations in Hydraulic Engineering (2 parts), by Professor T. C. Fidler.

The Steam-Engine and other Heat-Engines (3rd ed.), by J. A. Ewing, C.B.

Modern Guns and Gunnery (3rd ed.), by Brevet Col. H. A. Bethell, R.F.A.

Die Pressluftwerkzeuge, by P. Iltis; from the author.

Thermodynamics of the Steam-Engine and other Heat-Engines (6th ed.), by Professor C. H. Peabody.

American Producer Gas Practice and Industrial Gas Engineering, by Nisbet Latta.

The Marine Steam Turbine (3rd ed.), by J. W. Sothern.

Manual of Road Construction and Maintenance, by Major E. M. Paul, R.E.

Road Making and Maintenance (2nd ed.), by Thomas Aitken.

Engineering Construction in Steel and Timber (2nd ed.), by Professor W. H. Warren.

Bridge Engineering: Roof Trusses; by F. O. Dufour.

Standard Handbook for Electrical Engineers (3rd ed.), by a Staff of Specialists.

The Progress of a Century: or the Age of Iron and Steam, by Edwin Lawrence; The New Patent Law, being the Sections Relating to Patents of the Patents, Designs, and Trade Marks Act, 1883 (3rd ed.), by James Johnson and J. H. Johnson; Steam in Relation to Cornwall, by Sir E. Durning-Lawrence, Bart., M.P., and Reprint of The Miner's Friend, by Tho. Savery, 1702; Illustrated Souvenir of a Trip to Berlin and the Loewe Works, July 1900; from Mr. Edgar Worthington.

The Distington Multiple Boiler Explosion and other Multiple Boiler Explosions, by E. G. Hiller; from the author.

Drying Machinery and Practice, by T. G. Marlow.

The Kinematics of Machinery, by Professor F. Reuleaux (translated by Professor A. B. W. Kennedy).

The Modern Steam Engine, by John Richardson; from Mr. R. B. Glover.

Metallographie (German) (Parts 1–6), by Dr. W. Guertler; from the author.

OFFICIAL PUBLICATIONS.

British Isles.

Board of Trade Reports on Boiler Explosions; from the Board of Trade.

Report of the Board of Education for the year 1908–1909; Syllabuses applicable to Technical Schools, Schools of Art and other forms of Provision of further Education in England and Wales; from the Board of Education.

Seventh Annual Report of the Metropolitan Water Board, year ended 31st March 1910; from the Metropolitan Water Board.

Abridgments of Specifications: Period 1905–8, Nos. 1–6, 8–19, 21, 23–28, 30–33, 35–37, 39–43, 45, 47–49; 52 (1–2), 54, 56–59, 62, 63, 66, 67, 71–74, 76, 77, 84. Catalogue of the Library of the Patent Office (Authors); Illustrated Official Journal (Patents); from the Patent Office.

Africa.

Fifteenth Annual Report of the Rhodesia Chamber of Mines, for the year ended 31 December 1909; from the Rhodesia Chamber of Mines.

Report of the General Manager of Railways, for the year ended 31 December 1909; from the Central South African Railways.

Final Report of the Mining Regulations Commission, Vol. I, Report 1910; Annual Report of the Government Mining Engineer (Transvaal Mines Department) for the year ended 30 June 1909; Report on the Manufacture of Iron and Steel in the Transvaal, by F. W. Harbord; Report of the Bewaarplaatsen Commission, 1909; Report of the Power Companies Commission, 1909; from the Government of the Transvaal.

Australasia.

Australian Official Journal of Patents; from the Department of Patents in the Commonwealth of Australia.

Report of the Department of Public Works for the Year ended 30 June 1909; Annual Report of the Department of Mines, 1909; The Official Year Book, 1908-9; Report of the Chief Commissioner for the Year ended 30 June 1910; from the Government of New South Wales.

Annual Report of the Under-Secretary of Mines, 1909; Mining Journal; from the Government of Queensland.

Report of the Secretary for Mines, for year ending 31 Dec. 1909; from the Government of Tasmania.

Report on the working of the Government Railways and the Roebourne-Cossack Tramway for the year ended 30 June 1909; Geological Survey, Bulletin, No. 33; Report of the Department of Mines for the year 1909; Report on the working of the Government Railways for the year ended 30 June 1910; from the Government of Western Australia.

Canada.

Eighteenth Annual Report of the Bureau of Mines, 1909, Vol. XVIII, Part I; from the Government of Canada.

China.

List of Chinese Lighthouses, Light-Vessels, Buoys and Beacons, 1910; from the Inspector-General of Chinese Customs.

India.

Report of the Chief Inspector of Mines in India under the Indian Mines Act (VIII of 1901) for the year ending 31 December 1909; from the Government of India.

Classified Lists and Distribution Returns of Establishment, Indian Public Works Department, to 31 December 1909 and 30 June 1910; Classified Lists of State Railways, to 31 December 1909 and 30 June 1910; from the Registrar.

United States.

Report of the Chief of Ordnance, Vol. VI; Tests of Metals, etc., 1908; Annual Report of the Chief of the Bureau of Steam Engineering to the Secretary of the Navy for the fiscal years 1909 and 1910; from the Government of the United States of America.

Mineral Resources of the United States, 1908 (2 volumes); Bulletins, 386, 390, 391, 396–398, 400, 404–408, 414–428, 432; Water Supply and Irrigation Papers, Nos. 227, 233, 236–239, 241, 243–252; Professional Papers, Nos. 65 and 68; Thirtieth Annual Report, 1909; from the U.S. Geological Survey.

Official Gazette; from the United States Patent Office.

PAMPHLETS, &c. (in order received).

A New Experimental Method of investigating certain Systems of Stress, by G. H. Gulliver; from the author.

A Sketch of the Commercial Development during the last Three Hundred Years, 1609–1909, by H. de B. Parsons; from the author.

Oscillations de Lacet des Véhicules de Chemins de fer; Théorie des Déraillements; from the author, M. Georges Marié.

Water Supply; Copper v. Steel Fireboxes, by H. B. Lake and T. W. Lowe; from Mr. H. B. Lake.

Onderzoekings-uitkomsten in verbund met "het wezen der zandfiltratie," by J. M. K. Pennink; from Mr. J. F. E. Pennink.

Improvements in Resilient Wheels for Vehicles, by the Hon. R. C. Parsons; from the author.

Evaporation from Water Surfaces, by S. R. Lowcock; from the author.

The "Growth" of Cast Irons after Repeated Heatings, by Professor H. F. Rugan and Professor H. C. H. Carpenter, Ph.D.; from Professor H. C. H. Carpenter, Ph.D.

The Elastic Breakdown of Non-Ferrous Metals, by C. A. M. Smith; from the author.

Particulars of the Brennan Mono-rail System of Locomotion as exhibited at Gillingham, Kent, 1909–10; Official Catalogue of the Naval, Mercantile

Marine, and General Engineering and Machinery Exhibition, Olympia, London, 1910; Preliminary and Interim Report of the Inst. C.E. Committee on Reinforced Concrete; English and American Railroads compared, by E. B. Dorsey; Experiments on the Expansion of Continuous Rails, by A. J. Moxham; Two Papers on Express Trains (English), by E. Foxwell; Some Statistics of our English Express Trains, by A. W.; The Ventilation of the House of Commons, by Walter Yates; A Short Description of the Manchester Corporation Waterworks, by Sir J. J. Harwood; The Practical Application of the Modern Theory of Heat to the Steam Engine, by William Anderson; Catalogue of the Naval and Marine Engineering Collection in the Science Division of the Victoria and Albert Museum, South Kensington, 1899; Catalogue of the Mechanical Engineering Collection in the Science Division of the Victoria and Albert Museum, South Kensington, Part I (4th ed.) with Supplement, Part II (2nd ed.) with Supplement; from Mr. Edgar Worthington.

The Copper-Zinc Alloys: a study of Volume Changes, by Professor T. Turner and M. T. Murray; from Professor T. Turner.

Improvements in Two-stroke Cycle Internal Combustion Engines, Provisional Specification No. 10,136, A.D. 1909, by George Enderby and Henry Johnson; from Mr. Henry Johnson.

Presidential Address to the Association of Engineers-in-Charge, 1909–1910; Stresses and Strains in Girder-Work; from the author, Mr. Henry Adams.

MS. Particulars of workings of eleven compound 8 wheeled coupled Goods Engines; eleven simple 8 wheeled coupled Goods Engines; Non-Superheater and Superheater Engines (6 wheeled Goods); Consumption of Coal and Oil; Train, Engine, and Ton Miles, &c.; Tables A. B. C. D.; by Mr. George Hughes; from the author.

Congrès International des Chemins de fer, Sixième Session, Paris, 1900, Extraits du Bulletin 1–65, 67, 69; Calorimetrische Untersuchungen über den Kreisprozess der Gasmaschine (3 parts), by Dr. A. Slaby; from Mr. D. A. Louis.

Patents and Designs Act, 1907.

The Recovery of Tin by Bucket Dredgers: Some Recent Data from the Malay Peninsula; from the publishers.

The Electrification of the Ferndale Collieries, by W. H. Patchell; from the author.

Rapid Transit in the Future: The Kearney High-speed Railway, by E. W. C. Kearney; from the author.

Report on the Blackwell's Island Bridge, by F. C. Kunz and a Commission; from the Pennsylvania Steel Co.

Decimal Coinage, Weights and Measures: Should this Country adopt them? (2nd ed.), by Edwyn Anthony; from the author.

A Catalogue of Modern Works on Science and Technology (38th ed.).

A Comparison of the Problems presented respectively by the Dirigible and the Aeroplane; Aerial Automobilism; Aeronautical Engineering; The Pedrail; from the author, Dr. H. S. Hele-Shaw, F.R.S.

The Effect of Vanadium in Cast Iron, by J. K. Smith and W. L. Turner; from Mr. J. Kent Smith.

The Behaviour of Ductile Material under Torsional Strain, by C. E. Larard; from the author.

Impressions of America, 1908, by E. J. Crosier; from the author.

Autobus ou Tramway Électrique, by E. Shrapnell Smith; from the author.

Chadwick Lectures on Sanitation, University of London, 1907–8, by W. D. Scott-Moncrieff; from the author.

Les Turbo-Machines Multicellulaires et leurs Récentes Applications, by Professor A. Rateau; from the author.

Douglas' Two-Colour Logs and Anti-Logs, by G. C. Douglas; from the author.

Étude sur les Pistolets Automatiques, by E. Niotan; from the author.

Discussion of Mr. John Kirsopp's Paper on Coal-Shipment and the Laying-out of Staithe-Heads, with special reference to Anti-breakage Appliances; from Mr. John Kirsopp.

Report of the Advisory Committee for Aeronautics for the year 1909–10; from the Secretary to the Committee.

Field Station: Cavalry Type 1910. Marconi's Wireless Telegraph Co., Ltd.; from Capt. H. Riall Sankey.

Fires: Effects on Building Material and Permanent Elimination, by F. B. Gilbreth; from the author.

Census of Production, 1907 (4 parts).

Statistical Abstract for the Principal and other Foreign Countries in each Year from 1897 to 1907–8 (35th No.).

Auckland City and Suburban Electric Tramways: Report of the Royal Commission appointed to Inquire into the Efficiency of the Brakes, and Suitability of the Brake Systems Adopted; from Professor Robert J. Scott.

Reports on the Proposed Improvement of the Ports of Mejillones, Antofagasta, Iquique and Arica (with Plans), by Adam Scott; from the author.

Rapport sur un Loqueteau pour Voitures de Chemins de fer de M. Jacquin, by Professor E. Sauvage; from the author.

Proposed Norwich to Yarmouth Ship Canal: Ship Canal across England, by W. J. Botterill; from the author.

Report *re* Promenade and Street Improvement at Sandybank and Battery Square, Penzance, by Frank Latham; from the author.

Presidential Address to the Auctioneers' Institute of the United Kingdom, by Sir Robert Buckell; from the author.

Arbitration Procedure, by George Phillips; from the Auctioneers' Institute.

A New Torsion Testing Machine, by Professor W. E. Lilly, D.Sc.; from the author.

Metallurgical Bibliography, 1901-1906, by R. A. Peddie; from the author.

Indian Railways: the Work of Deputies, by a District Officer; from the author.

Minutes of Evidence and Report of the Departmental Committee on Machinery and Engineering Staffs at Poor Law Institutions (2 pamphlets).

Vice-Regal Commission on Irish Railways including Light Railways: Fifth and Final Report of the Commissioners, and Appendices to the First, Second, Third, Fourth (2 vols.), and Final Reports; from Mr. J. A. F. Aspinall.

Influence of Underground Waters on Health, by Baldwin Latham; from the author.

The following from the Engineering Standards Committee:—Fifth Report on Work Accomplished from 1st August 1908 to 31st July 1909; Third Report of the Locomotive Committee on Standard Locomotives for Indian Railways, No. 50; Report on British Standard Copper Conductors, No. 7 (2nd ed.); British Standard Specification for Portland Cement, No. 12 (3rd ed.); British Standard Specification for Wrought Iron for use in Railway Rolling Stock, "Best-Yorkshire" and Grades A. B. and C., No. 51; British Standard Specification for Structural Steel for Shipbuilding, No. 13 (4th ed.); British Standard Specification for Steel Conduits for Electrical Wiring, No. 31 (2nd ed.); British Standard Specification for Bayonet Socket Lamp Holders and Caps, No. 52.

The following from the Rector, Berlin Königlichen Technischen Hochschule:—Untersuchung über die Ursachen des Unterganges der verschollenen Fischdampfer, by Friedrich Moll; Ventilsteuerungen für Schiffsmaschinen, by Johannes Jahn; Fabrikorganisation mit spezieller Berücksichtigung der Anforderungen der Werftbetriebe, by Ludwig Gümbel; Die Entwicklung, der Eisenindustrie in Deutschland, by W. Mathesius; Elastische Formänderung des Schiffskörpers, by Richard Siemann; Verwendung des Heissdampfes in für Sattdampf gebauten Schiffsmaschinenlagen, by Rudolf Schmidt; Beiträge zur Bestimmung der Erweichungskoeffizienten natürlicher Bausteine, by Rudolf Schenck; Die Beanspruchungen des Rudergeschirrs auf Seeschiffen, by Hugo Schoeneich; Die dynamischen Wirkungen der Wellenbewegung auf die Längsbeanspruchung des Schiffskörpers, by Fritz Horn; Untersuchung der Kontinuität der Längsträger zweigleisiger Balkenbrücken, by Otto Birkenstock; Anwendung der modernen Organisations- grundlagen auf Klein- und Mittelbetriebe, by Gottlieb Peiseler; Versuche zur Ermittelung der günstigsten Arbeitsweise der Rundschleifmaschine, by Willy Pockrandt; Versuche über die Strömungsvorgänge in erweiterten und verengten Kanälen, by Heinrich Hochschild; Die Kugelfallprobe, by John J. Schneider; Die Technik der Verbrennung und Energie-Gewinnung aus städtischen Abfallstoffen, by Friedrich Meyer; Theorie und Konstruktion der Teillochwicklungen für Mehrphasengeneratoren, by Michael Seidner; Der Wärmedurchgang in Maischbottichen, by Max Berlowitz; Untersuchungen über Urbeitseignung und Leistungs-fähigkeit der Urbeiterschaft eines grossindustriellen Betriebes, by Stanislaw von Bienkowski.

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The Engineer's Year-Book, 1910, by H. R. Kempe; from the editor and proprietors.

Garcke's Manual of Electrical Undertakings, 1910.

International Catalogue of Scientific Literature (B=Mechanics, C=Physics)

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Shipowners, Shipbuilders, and Marine Engineers' Directory, 1910; from Mr. S. Richardson Blundstone.

Spons' Architects' and Builders' Pocket Price Book 1910, by Clyde Young and S. M. Brooks; from the publishers.

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Glasgow and West of Scotland Technical College, Glasgow; Calendar 1910–11, and Report 1910.
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City and Guilds of London Institute; Report 1910 and "The Central."
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Crystal Palace Engineering School Magazine (from Mr. J. W. Wilson).
East London College; Calendar 1910–11.
Imperial College of Science and Technology; Calendar 1910–11.
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University of Sheffield; Calendar 1910–11.

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7 framed photographs of the Machinery at the Metallurgical Works of the Campañia Huanchaca de Bolivia; from Mr. John McCool.

2 blue photographs of the Albert Edward Bridge over Severn at Buildwas; from Mr. W. H. Duncan.

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Framed photograph of the testing of cast iron girders at Coalbrookdale of the G.W.R. Bridge at Buildwas; from Mr. F. W. Monks.

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MS. Results of Experiments and Tests in connection with Paper read before the Inst. Mech. E. in May 1910, on *Comparison of the Tensile, Impact-Tensile, and Repeated-Bending Methods of Testing Steel*, by B. Blount, W. G. Kirkaldy, and Capt. H. R. Sankey; from Capt. H. Riall Sankey.

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*Manchester Steam Users' Association; Annual Report and Chief Engineer Memorandum.

*Marine Engineers, Institute of; Transactions.

*Metals, Institute of; Journal, and List of Members 1910.

*Mining Engineers, Institution of; Transactions.

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*Municipal and County Engineers, Incorporated Association of; Proceedings.

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*Naval Architects, Institution of; Transactions, and List of Members 1910.

*North of England Institute of Mining and Mechanical Engineers, Newcastle-on-Tyne; Transactions.

*North-East Coast Institution of Engineers and Shipbuilders, Newcastle-on-Tyne; Transactions.

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*Royal Artillery Institution, Woolwich; Journal.

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*Royal Cornwall Polytechnic Society, Falmouth; Report.

*Royal Dublin Society; Proceedings.

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*Royal Philosophical Society of Glasgow; Proceedings.

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*Royal Society of Arts; Journal.
*Royal Society of Edinburgh; Proceedings.
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*South Wales Institute of Engineers, Cardiff; Proceedings, and List of Members 1910.
*Staffordshire Iron and Steel Institute, Dudley; Proceedings.
*Surveyors' Institution; Transactions and Professional Notes.
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*West of Scotland Iron and Steel Institute, Glasgow; Journal.

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Victorian Institute of Engineers; Proceedings.

Austria.

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*Association des Ingénieurs sortis des Écoles spéciales de Gand; Annales.
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*Royal Society of Canada, Ottawa; Proceedings and Transactions.

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*Académie des Sciences, Paris; Comptes Rendus des Séances.

*Annales des Mines, Paris.

*Annales des Ponts et Chaussées, Paris.

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*L'Association Technique Maritime; Bulletin.

*Associations de Propriétaires d'Appareils à Vapeur, Paris; Compte Rendu des Seances.

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*Revue Maritime, Paris.

*Société d'Encouragement pour l'Industrie Nationale, Paris; Bulletin.

*Société Scientifique Industrielle de Marseille; Bulletin.

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*Zeitschrift des Vereines deutscher Ingenieure; *Mitteilungen über Forschungsarbeiten; Berlin.

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*Committee of the Locomotive, Carriage and Wagon Superintendents of Indian Railways, Madras; Proceedings.

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*Svenska Teknologföreningen, Stockholm.

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*American Institute of Mining Engineers, New York; Bulletin and Transactions.

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Cold Storage and Produce Review.
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*Electrical Engineer.
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*Marine Engineer.
*Mechanical Engineer.
*Mechanical World.
*Mining Journal.
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*Motor Traction.
*Nature.
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*Philosophical Magazine and Journal of Science.
*Plumber and Decorator.
*Practical Engineer.
Quarry.
*Railway Engineer.
*Railway Gazette.
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*Shipping World.
South African Engineering.
*Steamship.
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Surveying and the Civil Engineer.
The Syren and Shipping Illustrated.
*Textile Recorder.
Tramway and Railway World.
Vulcan.
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*Revue Universelle des Mines.

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Canadian Engineer.
Canadian Machinery and Manufacturing News.
Canadian Manufacturer.

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*Génie Civil.
*Revue générale des Chemins de fer.
*Revue Générale du Froid.
*Revue de Mécanique.
Technique Moderne.

Germany.

*Dinglers Polytechnisches Journal.
*Elektrotechnische Zeitschrift.
*Giesserei Zeitung.
*Glaser's Annalen.
Glückauf.
Der Ingenieur.
*Organ für die Fortschritte des Eisenbahnwesens.
Annalen der Physik.
Zeitschrift für Instrumentenkunde.
Zeitschrift für Maschinenbau und Schlosserei.
*Zeitschrift für Werkzeugmaschinen und Werkzeuge.

Holland.

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India.

Indian and Eastern Engineer.
Indian Industries and Power.
Railways.
Indian Textile Journal (English edition).

Italy.

*Giornale del Genio Civile.
L'Ingegneria Ferroviaria.

Switzerland.

*Revue Polytechnique Schweizerische Bauzeitung.

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*American Engineer and Railroad Journal.
*American Machinist.
*Brotherhood of Locomotive Firemen's Magazine.
*Castings.
*Electric Railway Journal.
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*Electrical World.
*Engineering News.
*Engineering Record.
*Foundry.
*International Marine Engineering.
Iron Age (from Mr. W. H. Maw, LL.D.).
Iron Trades Review (from Mr. W. H. Maw, LL.D.).
Machinery.
Motor Age.
*Physical Review.
Popular Mechanics.
*Power.
*Railway and Engineering Review.
Railway and Locomotive Engineering.
*Scientific American.
*Wood Craft.

The President, after formally moving "That the Annual Report be adopted," asked whether any member desired to ask any questions with regard to it.

No questions being asked, the motion for the adoption of the Report was put and carried unanimously.

The President announced that the Council had been considering the question of the Summer Meeting for 1911, and they had decided, in response to the desire of a number of the members, that it should be held upon the Continent; and, in order that the members might have an opportunity of seeing some engineering work which had been carried out by their Continental friends, it had been decided that the meeting next July should be held at Zürich. Although the meeting would not be held until July, the present early announcement would enable members to make their plans, and the Council hoped that in consequence a very large number would attend that Meeting.

The President then presented the "Starley Premium" to Mr. Lucien A. Legros, Member, for his Paper on "The Development of Road Locomotion in recent years." On making the presentation, which consisted of a certificate, a watch, a Zeiss prism binocular, some books, and a clock, the President congratulated the author on winning the premium.

The President announced that Mr. W. R. Eckart, Jun., Associate Member, the winner of the "Water Arbitration Prize" had selected the 11th Edition of the *Encyclopaedia Britannica* (29 vols.) on India paper bound in flexible leather, and that it would be forwarded to him in California.

The President next presented the prizes awarded by the Council for the best two Papers in the Graduates' Section read during the Session 1909–1910—to Mr. E. W. Moss for his Paper on "Some Notes on Materials under Combined Stresses," and to Mr. T. H. Sanders for his Paper on "The Commercial Testing of Railway Materials."

The President reported that the Ballot Lists for the election of Officers for the present year had been opened by a Committee of the Council, and that the following were found to be duly elected:—

PRESIDENT.

Edward B. Ellington,	London.

VICE-PRESIDENTS.

H. F. Donaldson, C.B.,	Woolwich.
Michael Longridge,	Manchester.

MEMBERS OF COUNCIL.

Dugald Clerk, F.R.S.,	London.
Sir Robert A. Hadfield, F.R.S.,	Sheffield.
Edward Hopkinson, D.Sc.,	Manchester.
George Hughes,	Horwich.
Henry A. Ivatt,	Doncaster.
Engineer Vice-Admiral Sir Henry J. Oram, K.C.B.,	London.
Captain H. Riall Sankey, R.E., ret.,	London.

The President announced that, to fill the vacancy caused by the election of Mr. Michael Longridge as a Vice-President, the Council had appointed Mr. William H. Patchell a Member of Council. He would retire at the next Annual General Meeting, in accordance with Article 25.

The Council for the present year is therefore as follows:—

PRESIDENT.

Edward B. Ellington,	London.

PAST-PRESIDENTS.

John A. F. Aspinall,	Manchester.
Samuel Waite Johnson,	Nottingham.
Sir Alexander B. W. Kennedy, LL.D., F.R.S.,	London.
William H. Maw, LL.D.,	London.
E. Windsor Richards,	Caerleon.
T. Hurry Riches,	Cardiff.
Percy G. B. Westmacott,	Ascot.
Sir William H. White, K.C.B., LL.D., D.Sc., F.R.S.,	London.
J. Hartley Wicksteed,	Leeds.

VICE-PRESIDENTS.

Henry Davey,	Ewell.
H. F. Donaldson, C.B.,	Woolwich.
Arthur Keen,	Birmingham.
Sir William T. Lewis, Bart., K.C.V.O.,	Aberdare.
Michael Longridge,	Manchester.
A. T. Tannett-Walker,	Leeds.

MEMBERS OF COUNCIL.

William H. Allen,	Bedford.
Archibald Barr, D.Sc.,	Glasgow.
Sir J. Wolfe Barry, K.C.B., LL.D., F.R.S.,	London.
George J. Churchward,	Swindon.
Dugald Clerk, F.R.S.,	London.
Sir Robert A. Hadfield, F.R.S.,	Sheffield.
H. S. Hele-Shaw, LL.D., F.R.S.,	London.
Edward Hopkinson, D.Sc.,	Manchester.
J. Rossiter Hoyle,	Sheffield.
George Hughes,	Horwich.

Henry A. Ivatt,	Doncaster.
Henry Lea,	Birmingham.
Robert Matthews,	Manchester.
Engineer Vice-Admiral Sir Henry J. Oram, K.C.B.,	London.
William H. Patchell,	London.
Walter Pitt,	Bath.
Thomas P. Reay,	Leeds.
Mark H. Robinson,	London.
Captain H. Riall Sankey, R.E., ret.,	London.
Professor W. Cawthorne Unwin, LL.D., F.R.S.,	London.
Wilson Worsdell,	Ascot.

The President said it was now his duty to invite his friend Mr. Ellington to take the Chair. Mr. Ellington was an all-round engineer who was known all over the world, and quite apart from that, there was no one in connection with the Institution who had done more for its credit and more for its organization than he had done. Leading a busy, active engineering life, Mr. Ellington had been willing to give up a great deal of time to the Committee work of the Institution; and as Chairman of the Finance Committee, Chairman of the Building Committee, and Chairman of other Committees which he need not mention, he had done an immense amount of useful work. He (Mr. Aspinall) rejoiced to think that Mr. Ellington was becoming the President, because he would know all the details of the work so thoroughly that he could put his fingers upon any point in connection with the Institution. Mr. Ellington had many friends, but he ventured to think that at the end of twelve months he would have many more, because the members would by that time have got to know him so well. There was nothing in life which was of such value to a man as the friends that he might possess. He was, therefore, satisfied that Mr. Ellington would look back to his period of

Presidency with the greatest pleasure, because he would have added so much to his circle of friends, and he would look back upon any work which he might have done at the Institution as more than compensated for by the advantages that he would obtain in that way. In asking Mr. Ellington to take the Chair he was sure that the members with himself (Mr. Aspinall) would wish him every possible prosperity. Before Mr. Ellington actually took the Chair, he desired to thank the Members of Council, the Members of the Institution, the Secretary and Officers of the Institution, and all those other gentlemen who had been so good to him during the period that he had had the honour to be the President of the Institution. He thanked everyone for the support they had given to him, and he asked that that support should be extended to his successor.

The Chair was then vacated by Mr. ASPINALL, and taken, amid hearty cheering, by Mr. ELLINGTON.

The PRESIDENT (Mr. EDWARD B. ELLINGTON) said it was difficult for him to express the feelings uppermost in his mind on commencing the occupation of the Chair. His friend, Mr. Aspinall, had spoken in far too flattering terms of the services that he had been able to render to the Institution. As a Mechanical Engineer, that Institution was very dear to his heart, as he was sure it was to all the members of it. The responsibilities attaching to the office of President were very great. The Institution had increased in numbers and in usefulness, and it was by no means at the end of its career. Its career of usefulness could be further extended, and it would be his endeavour, so long as he occupied the Chair, to do all that he could to foster its interests, and to serve the members in the way that they themselves would desire. He would not take up further time at present, as he would have an opportunity on a subsequent occasion of delivering an Address, which he hoped to make useful to the cause they all had so much at heart.

Dr. **William H. Maw**, Past-President, said that, as senior Past-President present at the meeting, he had to perform the very pleasant task of proposing a hearty and cordial vote of thanks to the retiring President, Mr. John A. F. Aspinall, for his conduct of the affairs of the Institution during his period of office. All the members thoroughly knew with what unfailing courtesy and admirable tact Mr. Aspinall had controlled the Meetings, and they all appreciated very greatly the valuable contributions to the discussions with which he had from time to time favoured them. Those were all facts of common knowledge, and it was quite unnecessary that he should dwell upon them. He wished, however, to say a few words about some of the other duties of the President which perhaps were not always so generally appreciated; he referred particularly to the organization of the Summer Meetings. Those Meetings formed a most important item in the annual programme, and had from the first been a distinguishing feature of the Institution. As the membership of the Institution had grown, so had the attendances at those Meetings; and with that increase of attendance there had also grown the difficulty of making arrangements which would be thoroughly satisfactory to those members taking part in the gatherings. A very large part of those arrangements had to be settled by the President. The Presidents of the Institution had always, so far as his knowledge went, been backed up most loyally by their colleagues on the Council, and by the staff of the Institution; but in connection with the Summer Meetings it was inevitable that there should be a very large number of details, some of them exceedingly important, which must be left for settlement by the President for the time being. During the two years that Mr. Aspinall had occupied the Chair, two Summer Meetings had been held of a very notable character. First of all there was the Meeting at Liverpool, which was a record Meeting, being attended by a far larger number of members than any other the Institution had ever held, and it was carried out in a way which gave the greatest pleasure to all who took part in it. To his mind perhaps the most interesting feature of the Liverpool

Meeting was the fact that it afforded most ample evidence of the high esteem and warm regard with which Mr. Aspinall was regarded in the city and district where he had worked so well for many years past. He was sure that the way in which the members were received in Liverpool testified to that regard in the clearest manner; and he thought all the members of the Institution who were present at Liverpool felt proud of the way in which their President's attributes were recognized. Again last year, 1910, another notable Summer Meeting was held, partly at Birmingham and partly in London, in conjunction with a number of their friends from the other side of the Atlantic. He would not be betraying any secrets when he said that the organization of that Meeting was a source of very grave anxiety to those who were responsible for it. In 1904, when a number of the members of the Institution went to the United States, they received from the members of the American Society of Mechanical Engineers a welcome and hospitality which could only be described as magnificent. When, therefore, the Council of the English Institution heard that a return visit was to be paid by the American Society of Mechanical Engineers, they felt a very great responsibility was placed upon them, and that nothing they could do in the way of showing hospitality and making arrangements which would contribute in the utmost degree to the comfort and enjoyment of their visitors would be too great. He did not intend to go into any details, but he was glad to say that, in the end, the result they desired was fairly attained, and he had every reason to believe that their American visitors left this country with very pleasant recollections indeed of their visit to England. But the carrying out of those arrangements involved a more than ordinary strain upon the President for the time being, and that extra work came at a time when Mr. Aspinall, owing to an unfortunate accident, ought really to have been taking a rest, and not working either for the Institution or for anybody else. All the members knew, however, how Mr. Aspinall rose to the situation; he shirked no work to make the Meeting thoroughly successful, and the members undoubtedly owed him a most special debt of gratitude for the manner in which he had acted as their representative. Dr. Maw did not think it was necessary for him to say any more, and he would therefore conclude by moving a most hearty vote of thanks to Mr. Aspinall for his conduct in the Chair during the past two years, and for his energetic work in forwarding the interests of the Institution.

Mr. A. T. TANNETT-WALKER, Vice-President, said it gave him more than ordinary pleasure to second the proposition so ably moved by Dr. Maw. When the Institution of Mechanical Engineers required a first-rate President and there was a great deal of work to be done they selected his friend, Mr. Aspinall; and when Mr. Aspinall's Company required a General Manager, knowing how thoroughly clever and competent mechanical engineers were, they selected Mr. Aspinall. No greater compliment could have been paid to mechanical engineers than that appointment. He asked the members to show in the heartiest possible manner how highly they appreciated the valuable services Mr. Aspinall had rendered. Some of the members were not aware of the extent of those services, but as a matter of fact Mr. Aspinall had worked hard in doing his own work and the work of the Institution.

The resolution was carried by acclamation.

Mr. JOHN A. F. ASPINALL, Past-President, in reply, most heartily thanked Dr. Maw, Mr. Tannett-Walker and the members of the Institution for the way in which the resolution had been proposed and carried. He assured them that the work he had done had been of the greatest pleasure to himself. He had been very proud to be the President of the Institution. If the members would look at the marble slab in the Entrance Hall of the Institution, they would see upon it the name of his old chief and old friend, John Ramsbottom, who was the chief engineer at Crewe when he (Mr. Aspinall) went there to serve his time. He little thought in those early days that he would ever succeed Mr. Ramsbottom in the Chair of the Institution. He had always felt that Mr. Ramsbottom was one of the finest men the Institution ever possessed, and on that account alone he felt a measure of pride in succeeding to the Chair, which he could hardly tell the members how much he appreciated. That he had been successful in carrying out the duties of the President of the Institution was due entirely to the support, the kindness, and the consideration of his colleagues. It was all very well for Dr. Maw to point out that the duties of the President were arduous, but on the other hand, those who assisted him had to put their backs into the work and help him in every possible way. But after all, the work had its compensations, because as he had been pointing out to his friend, Mr. Ellington, it enabled one to see many more men and to make many more friends, and he felt that in leaving the Chair he was not leaving those friends. He cordially thanked the members for their great kindness to him.

Mr. P. J. COWAN, Member, moved "That Mr. Robert A. McLean, F.C.A., of 1 Queen Victoria Street, London, E.C., be reappointed to audit the accounts of the Institution for the present year at the remuneration of fifty guineas." He said that Mr. McLean had served the Institution in the capacity of auditor for many years and always to its satisfaction; and the members in giving expression to their opinion that evening would, he hoped, simply give a proof of their continued confidence in Mr. McLean's qualifications for the necessary work of auditing the accounts of the Institution.

Mr. E. G. CONSTANTINE, Member, seconded the motion, which was carried unanimously.

The Discussion upon Messrs. DIXON and BAXTER'S Paper on "Modern Electrical Dock-Equipment, with special reference to Electrically-operated Coal-Hoists" was resumed and concluded.

The Meeting terminated at Ten o'clock. The attendance was 137 Members and 54 Visitors.

THE ENERGY-DIAGRAM FOR GAS.

BY PROFESSOR F. W. BURSTALL, *Member*, OF THE UNIVERSITY OF BIRMINGHAM.

[*Selected for Publication.*]

The general tendency among engineers in the application of thermodynamics is to resort to graphical methods for solving the various problems connected with the behaviour of steam. The best known of these charts is the now familiar temperature-entropy diagram, and later the two diagrams of Mollier, which lend themselves to the treatment of the properties of superheated steam when the now accepted values of the specific heat are made use of, and in which the velocity of discharge of steam at the end of the adiabatic expansion can be obtained by a single measurement—a matter of importance in the problems of the steam-turbine.

Graphical methods have not so far been widely employed in connection with the internal-combustion engine, the reason being that with the specific heat of the so-called permanent gases taken as constant, the calculations are simple and readily performed. It is now universally conceded that the specific heat of various gases which form the working substance of an internal-combustion engine is not constant, but varies with the temperature.

The most recent, and certainly the most accurate, determination of the specific heats of nitrogen, carbon dioxide, and water vapour are those of Holborn and Henning,* who made a direct determination over a range of temperature up to 1,400° C. (2,552° F.), with the result that the specific heat of nitrogen was found to vary directly with the temperature, while in the cases of carbon dioxide and water vapour a more complicated formula has to be used. For this reason it seemed desirable to consider nitrogen alone; the values for other gases, such as oxygen and air, are readily obtained from those of nitrogen by the fact that the product of the specific heat and molecular weight is constant for such gases. The units employed throughout are English, with the exception that temperature is measured on the Centigrade scale, which is much more convenient when dealing with such high temperatures as are found in the internal-combustion engine. The temperatures are absolute, that is, measured from a point 273° below the zero of the Centigrade scale.

The values of the true specific heat of nitrogen at an absolute temperature, T, are given by the following:—

$$K_p = 0\cdot2246 + 0\cdot000038\ T.$$

$$K_v = 0\cdot1541 + 0\cdot000038\ T.$$

The thermal unit being the heat required to raise one pound of water through one degree Centigrade, the mechanical equivalent of one thermal unit being 1,400 foot-pounds.

The connection between pressure, volume, and temperature is given by:—

$$PV = 98\cdot86\ T.$$

In order to represent graphically the thermal state of any gaseous substance, any two of its properties may be used. For the vertical and horizontal scales, the most common scales employed are the pressure and volume, as these are obtained direct from the indicator diagram. To obtain from the pressure-volume diagram the heat added and rejected during the various portions of the cycle, calculations have to be performed which, when the variability of the specific heat is taken into account, are both difficult and laborious to carry out. The energy-chart has been constructed in order to simplify and enable all calculations in connection with the internal-combustion engine to be made with the aid of a pair of compasses alone.

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* Annalen der Physick, XIII. 1907.

The formulæ for the various heat additions for gases are given in the Proceedings,* but for the sake of completeness they are repeated here.

Let the two specific heats be given by

$$K_p = b + s\,T \quad \text{and} \quad K_v = a + s\,T$$

per unit weight. The heat added at constant volume between the temperatures T_1 and T_2 is given by

$$\int_{T_1}^{T_2} K_v dT = a\,(T_2 - T_1) + \frac{S}{2}\,(T_2^2 - T_1^2);$$

and as no work is done, this also represents the change of internal energy between the given temperatures. The heat added while the gas is at constant pressure is :—

$$\int_{T_1}^{T_2} Kp dT = b\,(T_2 - T_1) + \frac{S}{2}\,(T_2^2 - T_1^2).$$

It is more convenient for the applications to the energy-diagram to express this result in another form. Heat added = work done + change of internal energy.

If the change be at constant pressure, the work done is :—

$$\int_{v_1}^{v_2} p dv = p\,(v_2 - v_1),$$

where p is the given pressure, v_1 and v_2 the initial and final volumes corresponding to the temperatures T_1 and T_2; the conditional equation of gases being $pv = RT$ the work done

$$= R\,(T_2 - T_1).$$

There now remain only two important cases of heat addition—the isothermal or constant temperature change, and the adiabatic or change without addition or loss of heat.

In an isothermal change the heat added is the work done, and the variable specific heat has no influence, the work done per unit weight being

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* Proceedings I. Mech. Eng., 1901, pages 1040, 1041.

$$RT \log_e \frac{p_1}{p_2},$$

where T is the temperature, p_1 and p_2 the initial and final pressures respectively.

If an amount of heat δq be added to unit weight of gas, then

$$\delta q = K_v \left(\frac{\delta T}{\delta p}\right) \delta p + K_p \left(\frac{\delta T}{\delta v}\right) \delta v;$$

but as:— $$pv = RT,$$

$$\frac{\delta T}{\delta v} = \frac{p}{R} \text{ and } \frac{\delta T}{\delta p} = \frac{v}{R};$$

or $$\delta q = K_v \frac{v}{R} \delta p + K_p \frac{p}{R} \delta v.$$

In an adiabatic curve no heat is added, hence $\delta q = o$, or with the above equation:—

$$o = (a + sT)\, v\delta p + (b + sT)\, p\delta v.$$

$$o = av\delta p + bp\delta v + (v\delta p + p\delta v)\frac{pvs}{R}.$$

$$o = \frac{a\delta p}{p} + \frac{b\delta v}{v} + \frac{S}{R}(v\delta p + p\delta v).$$

The integral of this is given by:—

$$a \log_e p + b \log_e v + \frac{spv}{R} = \text{constant}.$$

If this is expressed in terms of p and T only:—

$$b \log_e T - (b - a) \log_e p + s\, T = \text{constant}.$$

This equation can only be solved by fixing the value of T, and thence obtaining the value of p. The particular quantities chosen for the vertical and horizontal ordinates are the internal energy of the gas and the pressure, the diagram, Fig. 1, being drawn for one pound of nitrogen. The origin is the zero of absolute temperature, and height corresponds to the total energy equivalent to 2,000° C.; the horizontal scale is in pounds per square inch, and extends to a pressure of 700 lb. per square inch.

With the given data the internal energy $= 0{\cdot}1541\ T + 0{\cdot}000019\ T^2$.

The values of this for every 100 degrees are plotted vertically; the temperatures are also plotted on the left-hand side of the

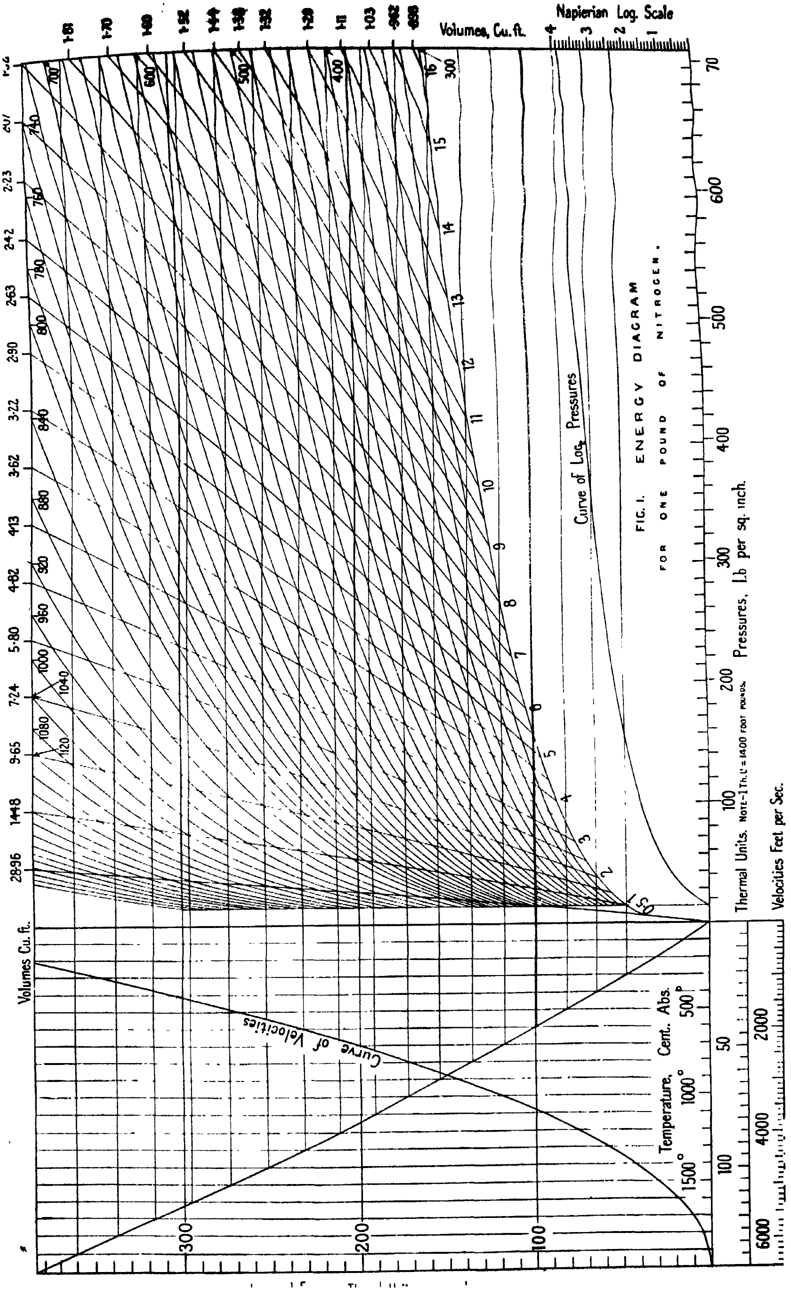


FIG. I. ENERGY DIAGRAM FOR ONE POUND OF NITROGEN.

pressure zero, so as to obtain a curve which connects the temperature and internal energy. If the specific heat had been taken as constant this curve would have been a straight line, but being variable with the temperature it is slightly curved, and shows graphically the influence of the variability. The scale of temperatures is shown on the base at the left of the zero of pressure, and serves to connect the pressure and temperature at any point of the diagram.

As nearly all the cycles used in the internal-combustion engine contain either adiabatics or isothermal curves, it is necessary to draw the curves on the diagram.

The adiabatic curve is given by

$$\text{Constant} = \log_{10} T - 0\cdot314 \log_{10} p + 0\cdot0000734\ T.$$

A series of (horizontal) curves are drawn from this formula, starting in each case with an absolute pressure of one atmosphere or 14·7 lb. per square inch, the initial temperatures starting at 300° C., and thence by intervals of 20° to 800°; after that by intervals of 40° C. to 1,600° C.

In the construction of the diagram, T is fixed and p calculated; from the temperature curve the value of the corresponding internal-energy can be fixed, and thus p can be plotted. As the vertical ordinate of internal energy depends on temperature alone, it follows directly that horizontal lines represent isothermal curves.

As changes at constant volume are frequent, it is necessary to draw a series of curves which serve to connect the pressure and internal energy when the volume is kept constant. As

$$pv = 98\cdot86\ T,$$

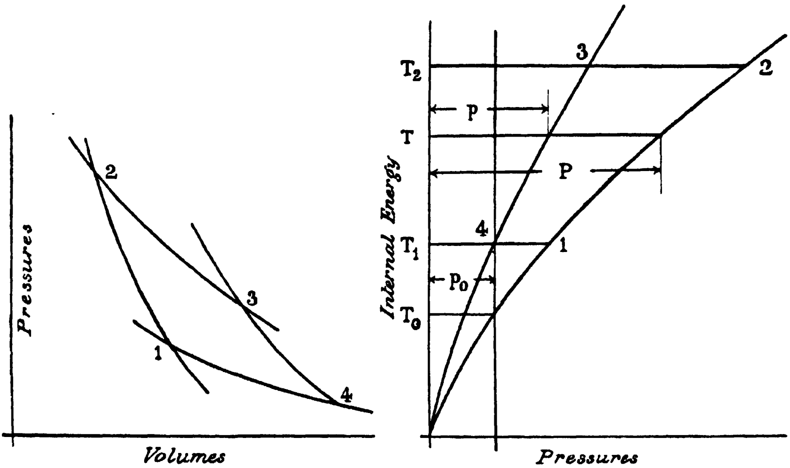
$\frac{98\cdot86\ T}{p}$ is constant for any given volume; and as when plotting the adiabatic, T being given, the internal energy can at once be found on the diagram, p can thus be plotted.

The first constant-volume line is drawn through an initial temperature of 300° absolute and a pressure of one atmosphere; this corresponds to a volume of 14·48 cubic feet. Other volume-lines drawn are those in which the given volume is an even multiple of the first volume, so as to facilitate calculations involving given compression ratios. Any volume lying between two given volumes can be readily obtained by interpolation, that is, by dividing the horizontal space between the two volume-lines in the required ratio. Thus being given any two of the four quantities—pressure, volume, temperature, and internal energy—it is a simple matter to obtain the other two by inspection on the diagram.

It will be convenient here to give some of the general properties of curves on the diagram, which may be used to check the correctness of the calculations and plotting.

Take a Carnot cycle between two given temperatures, T_1 and T_2, which is shown on the energy-diagram, Fig. 2, by the points 1, 2, 3, 4, and consider a horizontal line corresponding to a temperature T drawn to cut the two adiabatics at pressures p and P. If p_0 be taken as the pressure of one atmosphere, then the adiabatic curve 3, 4 will be given by

Fig. 2.—*Carnot Cycle.*



$$b \log_e T - (b - a) \log_e p + s\,T$$

The adiabatic 1, 2 is given by

$$\begin{aligned} &b \log_e T - (b - a) \log_e P + s\,T \\ &= b \log_e T_0 - (b - a) \log_e p_0 + s\,T_0, \end{aligned}$$

where T_0 is the temperature which corresponds to a pressure of p_0 on this adiabatic.

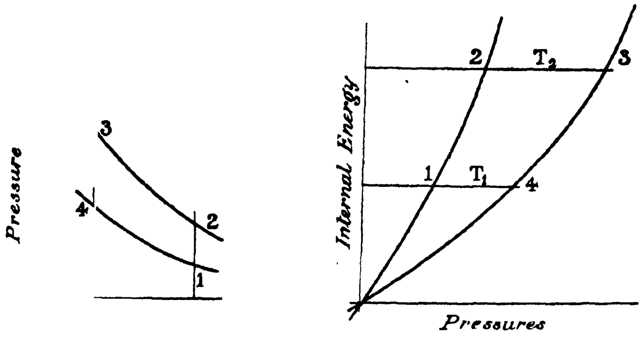
If the first equation be subtracted from the second, the terms in T cancel and

$$(b - a) \log_e \frac{p}{P} = b \log_e \frac{T_0}{T_1} + s (T_0 - T_1),$$

that is, the value of $\frac{p}{P}$ remains constant for any two given adiabatic curves.

A similar relation exists between any two constant-volume lines. Consider two constant-volume lines 1, 2 and 3, 4, and two

G. 3.—*Stirling Cycle.*



sothermals at temperatures T_1 and T_2, Fig. 3, then

and $\qquad p_1v_1 =$

but the volumes being constant

$$v_1 = v_2,\ v_4 = v_3$$

that is

$$\frac{}{p_1} = \frac{}{p_4} \text{ or } \frac{}{p_2} = \frac{}{p_1}$$

that is, the ratio of the pressures between any two constant-volume lines remains constant.

To obtain the heat added during an isothermal expansion, which per pound is

$$RT \log_e \frac{p_2}{p_1},$$

where T is the temperature at which heat is added, and p_2 and p_1 the initial and final temperatures, two other scales are employed.

The value of RT in thermal units is shown on the left-hand side of the pressure zero; also on the pressure base is plotted a curve of the logarithms of the pressures, so that to find the value of $\log_e \frac{p_2}{p_1}$ it is only necessary to scale the vertical distance on the logarithm curve between the two given pressures. The heat added during an isothermal expansion is the product of the two quantities so found.

The most valuable use of the diagram is shown by considering an adiabatic expansion. In this case the work done is entirely at the expense of the internal energy. As the latter is the vertical ordinate, the work done is obtained by measuring the vertical distance between the initial and final points on the expansion. In the same manner the heat added while the volume is kept constant is obtained from the vertical distance between the initial and final temperatures. The heat added and the work done under a constant pressure change are readily obtained from the diagram, the heat added being the sum of the change of internal energy and the work done. The latter quantity is $R(T_2 - T_1)$, where T_1 and T_2 are the initial and final temperatures. This quantity is given by the horizontal heat scale.

It is possible by means of another curve on the diagram to find the velocity of discharge of a gas expanding adiabatically through a nozzle. In this case the internal energy is converted into velocity, so that $V^2 = 2g\,I$, where V is the velocity and I the change of internal energy when expressed in work units.

On the left-hand side of the diagram a curve is constructed in which the vertical scale is the internal energy and the horizontal scale the velocity. To obtain the velocity for a given expansion the vertical distance is scaled up from the zero of internal energy; the horizontal distance corresponding to this is the required velocity.

It is a simple matter to transfer any indicator diagram on to the energy-diagram by multiplying the volumes on the indicator diagram by a factor which is the reciprocal of the charge weight; the pressure and volumes may then be plotted direct on the energy-diagram. In this manner an entire indicator-diagram may be transferred to the energy diagram, and the changes in the internal energy readily determined.

Curves of the form PV^n = constant are readily studied, as in this case the work done per pound is—

$$\frac{R(T_2 - T_1)}{n - 1}.$$

The numerator is already given on the horizontal heat scale; this, when divided by the known value $(n - 1)$, gives the work done. The heat added or lost is obtained by adding or subtracting the work done from the change of internal energy.

In the Third Report to the Gas-Engine Research Committee,* Appendix I, will be found the case of a charge expanding with a loss of heat, following the same form of law as the change of the specific heat itself; by the same reasoning as in the case of obtaining the equation to an adiabatic, the expansion curve takes the form—

$$\log_e T - \frac{b - a}{b - k} \log_e p + \frac{s - \sigma}{b - k} T = \text{constant},$$

where the heat leaking out is given by

$$k(T_2 - T_1) + \frac{\sigma}{2}(T_2{}^2 - T_1{}^2).$$

Also the work done is given by

$$(a - k)(T_2 - T_1) + \frac{s - \sigma}{2}(T_2{}^2 - T_1{}^2).$$

In nearly every case that has so far been examined of actual indicator diagrams, it would appear that if $k = \frac{a}{n}$, then $\sigma = \frac{s}{n}$ where n is greater than unity.

The work done then becomes—

$$\left[a(T_2 - T_1) + \frac{s}{2}(T_2{}^2 - T_1{}^2)\right]\left(1 - \frac{1}{n}\right).$$

This is a given fraction of the internal energy, and may be read direct from the diagram.

The best and most instructive illustration of the utility of the diagram is to consider a number of examples of different heat-engine cycles that have been employed, considering not only those which are in use at the present time, but also those cycles which have been discarded for practical reasons, but which are full of interest for the student of applied thermo-dynamics.

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* Proceedings, I. Mech. E., 1908, Part I, page 18.

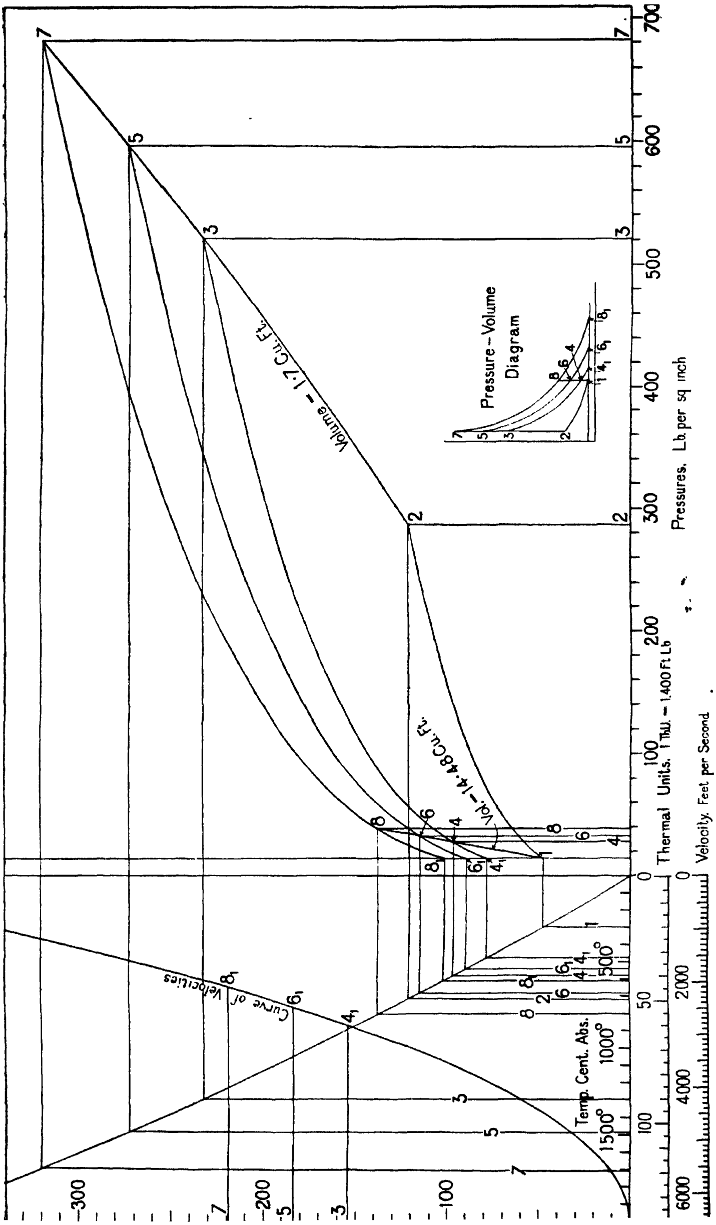


Fig. 4.—Gas-Engine Cycle.

The illustration in Fig. 4 (page 181) is the so-called perfect gas-engine cycle, which consists of adiabatic compression until the volume is reduced by a given ratio, then the addition of heat at constant volume until some predetermined pressure or temperature is reached; then there is adiabatic expansion until the initial volume, where heat is rejected at constant volume until the initial temperature is reached which completes the cycle.

In the particular example chosen the initial pressure at the end of the suction stroke is taken as 1 atmosphere or 14·7 lb. per square inch, the initial temperature 300° absolute or 27° C., the compression ratio being 8·5. Three special cases of addition of heat are considered, so that the maximum temperatures reached are respectively 1,300°, 1,480°, 1,720°, all being absolute. The volume of 1 lb. of nitrogen under a pressure of 1 atmosphere and at a temperature of 27° C. is shown to be 14·48 cubic feet, and is denoted by the symbol 1 on the lowest adiabatic.

In order to make the diagram clear, the ordinary pressure-volume diagram is drawn with the same numbering as in the energy-diagram. From point 1 to 2 there is adiabatic compression, until the volume is $\frac{1}{8\cdot 5}$ times its initial volume, or 1·70 cubic feet. The pressure and temperature are then read direct from the scales, being 287 lb. per square inch and 720° absolute, or 447° C.; the work done during compression is the vertical distance between points 1 and 2 measured on the vertical heat scale, and amounts to 73 thermal units; from 2 to 3 heat is added at constant volume until the given temperature, 1,300° absolute, is reached, the pressure being 521 lb. per square inch; the heat added during a constant-volume change, being the internal energy, is the vertical distance between 2 and 3, or 112 thermal units.

From 3 to 4 adiabatic expansion takes place until the original volume of 14·48 cubic feet is reached; this gives the exhaust pressure as 28 lb. per square inch, and the temperature as 580° absolute, or 307° C., the heat rejected to exhaust is the vertical distance 4 to 1, or 49 thermal units; hence the work done amounts to 112–49, or 63 thermal units, and the efficiency is—

$$\frac{63}{112} = 56\cdot 2 \text{ per cent.}$$

The gross work done during expansion is the vertical distance 3 to 4, or 136 thermal units.

The mean pressure is found by considering the cylinder volume, that is, the difference between the volumes at suction and end of compression, or 12·78 cubic feet. The work done in foot-lb. is 63 × 1,400 or 88,250; the mean pressure 6,920 lb. per square foot, or 48·0 lb. per square inch.

If the expansion be continued, atmospheric pressure is reached at the point 4_1 on the diagram, the temperature being 480° absolute or 207° absolute; the heat rejected to exhaust is formed of two portions, the change of internal energy 4 to 1, or 30·8 thermal units, together with work done under constant pressure scaled from the horizontal heat-scale, that is, 11 thermal units, the total being 41·8 thermal units, the net work done being now 70 thermal units and the efficiency $\frac{70}{112} = 62 \cdot 5$.

It is of interest to consider the velocity with which gas would be discharged after adiabatic expansion through a nozzle. The vertical distance 3 to 4 is the available energy to be converted into velocity; this is equal to 154 thermal units, and is plotted vertically upwards on the internal-energy scale; a horizontal ordinate to the velocity curve gives the velocity, which is equal to 3,720 feet per second; had the discharge taken place at the back pressure of 28 lb. per square inch absolute, the velocity would have been 3,500 feet per second.

With the same compression, but adding heat until the temperature is 1,480° absolute, point 5 is obtained, the pressure being 595 lb. per square inch, the heat added being the vertical height 5, 2, and amounting to 152 thermal units; adiabatic expansion to the initial volume gives point 6, at which exhaust commences, the pressure 33 lb. per square inch absolute and the temperature 680° absolute or 407° C.; the heat rejected to exhaust is the vertical height 6 to 1, or 67 thermal units; the work done is 152–67, or 85 thermal units, the efficiency being $\frac{85}{152}$, or 55·8 per cent. The gross work done during expansion is the height 5 to 6, or 157 thermal units.

The mean pressure is obtained as before, as the net work is 85 × 1,400 foot-lb. or 119,000; the volume is 12·78 cubic feet, hence the mean pressure is 9,325 lb. per square foot, or 64·7 lb. per square inch.

Complete expansion gives 6_1, with a temperature of 540° absolute or 267° C.; the heat rejected is 42 thermal units in internal energy and 16 thermal units from the work done during constant pressure; the total heat rejected being 58 thermal units, the net work done is 94 thermal units, the efficiency being $\frac{94}{152}$, or 61·8 per cent.

The velocity of discharge at atmospheric pressure after adiabatic expansion is 4,080 feet per second; had the discharge taken place at the back pressure, 33 lb. per square inch absolute, the velocity would have been 3,790 feet per second.

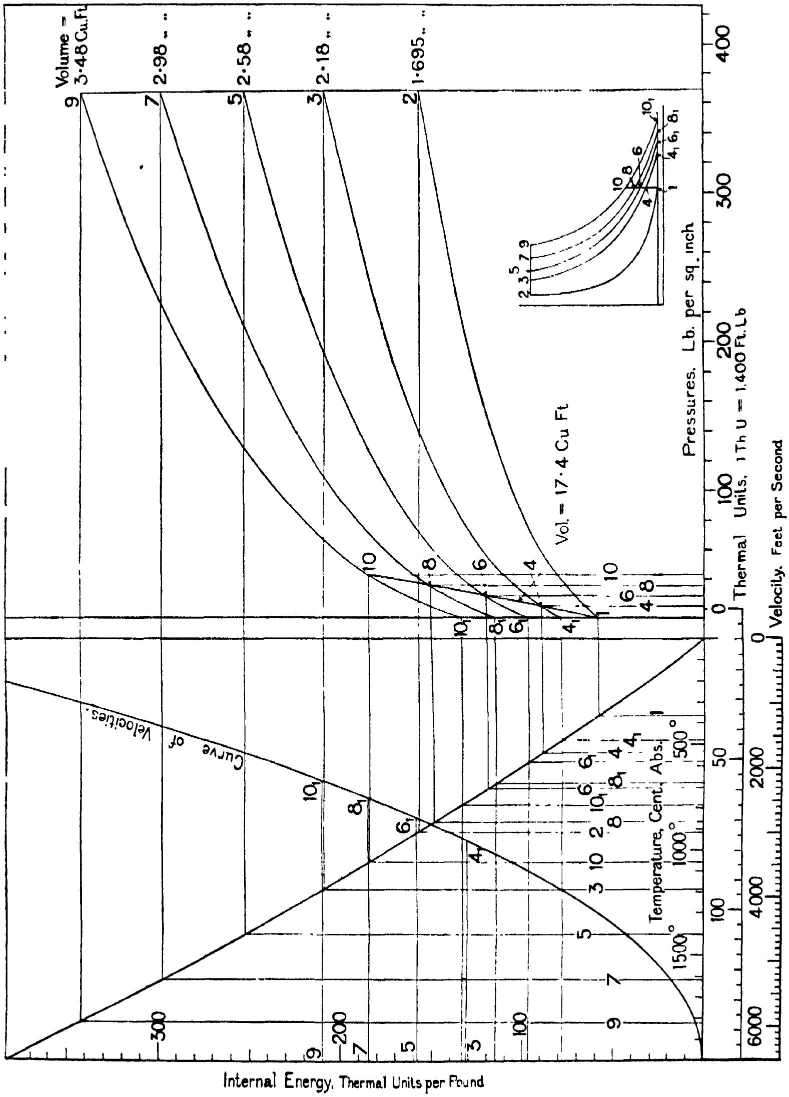
In the third case the maximum temperature reached is 1,810 absolute, giving point 7, at which the pressure is 682 lb. per square inch; the heat added is the vertical height 2 to 7, or 199 thermal units.

Adiabatic expansion to the original volume gives point 8 for the exhaust, the pressure being 39 lb. per square inch and temperature 800° absolute or 527° C.; the heat rejected is the vertical 1 to 8, or 90 thermal units; hence the work done is 199 – 90, or 109 thermal units, the efficiency being $\frac{109}{199}$, or 54·8 per cent. The gross work done on expansion is the height 7 to 8, or 182 thermal units. The mean pressure obtained from the work done is 109 × 1,400 foot-lb. or 152,800 foot-lb.; hence mean pressure is 12,200 lb. per square foot, or 85 lb. per square inch.

Complete expansion to atmospheric pressure gives point 8_1, the temperature of which is 610° absolute or 337° C. The heat rejected is made up of 54 thermal units of internal energy and 23 thermal units of work done at constant pressure, or a total of 77 thermal units; the work done in this case is 122 thermal units, and the efficiency $\frac{122}{199}$, or 61·3 per cent.

The velocity of discharge corresponding to atmospheric pressure and adiabatic expansion is 4,440 feet per second, while had the

FIG. 5.—*Diesel Cycle.*



discharge taken place at the back pressure of 39 lb. per square inch absolute it would have been 4,060 feet per second.

Fig. 5 (page 185) gives the cycle in the case of an engine where the heat addition is entirely at constant pressure, as is the case in the well-known Diesel engine.

The given conditions in the particular example chosen are an initial pressure of 1 atmosphere and a temperature of 360° absolute; the compression is the same in all cases, being 368 lb. per square inch absolute, the temperature at the end of compression being 920° absolute or 647° C.

The compression being adiabatic, the work done is equal to the change of internal energy between points 1 and 2, which is equal to 98 thermal units. In the first case heat is added at constant pressure until the temperature is 1,090° absolute. The change of internal energy between points 2 and 3 is equal to 52 thermal units, while the work done under constant pressure is 19 thermal units, making a total heat addition of 71 thermal units.

Adiabatic expansion to the original volume gives an exhaust pressure at point 4 of 22 lb. per square inch absolute, and a temperature of 540° absolute or 267° C.; the heat rejected is the distance 4 to 1, or 31 thermal units; the work done is, therefore, $71-31$, or 40 thermal units; hence the efficiency is $\frac{40}{71}$, or 56·3 per cent.

The mean pressure is readily obtained from the volumes at points 1 and 2, namely, 17·4 cubic feet and 1·69 cubic feet respectively; hence the cylinder volume is 15·7 cubic feet; the mean pressure is $\frac{40 \times 1{,}400}{15{\cdot}7}$, or 3,570 lb. per square foot, which is 24·8 lb. per square inch. The work done during expansion is the vertical height 3, 4, or 119 thermal units.

If adiabatic expansion be continued until atmospheric pressure is reached at 4_1, the temperature is 480° absolute or 207° C.; the heat rejected to exhaust is 20 thermal units from the internal energy, while the work done under constant pressure is 8·5 thermal units, making a total of 28·5 thermal units. The work done is, therefore, 42·5 units and the efficiency 60 per cent. The velocity with which the gas would be discharged after adiabatic expansion is 3,440 feet per second, while had it been discharged at a back pressure of 22 lb. per square inch absolute the velocity would have been 3,300 feet per second.

In the second case, heat is added at constant pressure until the temperature is 1,400° absolute at point 5, corresponding to a volume of 2·58 cubic feet. The change of internal energy between points 2 and 5 is 96 thermal units, while the work done between the same points is 34 thermal units, making a total heat addition of 130 thermal units. Adiabatic expansion to the original volume gives point 6 at which exhaust begins, being a pressure of 30 lb. per square inch and a temperature of 700° absolute or 427° C.; the heat rejected between points 1 and 6 is 61 thermal units, giving the work done as 69 thermal units, hence the efficiency is 53 per cent.

The mean pressure is $\frac{69 \times 1{,}400}{15 \cdot 7}$, or 6,150 lb. per square foot, that is, 42·7 lb. per square inch.

The work done during expansion, namely, the vertical height 5 to 6, is 133 thermal units. Complete expansion to atmospheric pressure gives point 6_1, corresponding to a temperature of 580° absolute or 307° C. The heat rejected is 38 thermal units of internal energy, and the work done at constant pressure 15 thermal units, giving a total of 53 thermal units; the work done is 130 − 53, or 77 thermal units; the efficiency is $\frac{77}{130}$, or 59·2 per cent. The velocity of discharge corresponding to point 6_1 is 3,800 feet per second, and corresponding to point 6 is 3,480 feet per second.

In the third case, heat is added until a temperature of 1,620° absolute is reached, point 7 giving a volume of 2·98 cubic feet.

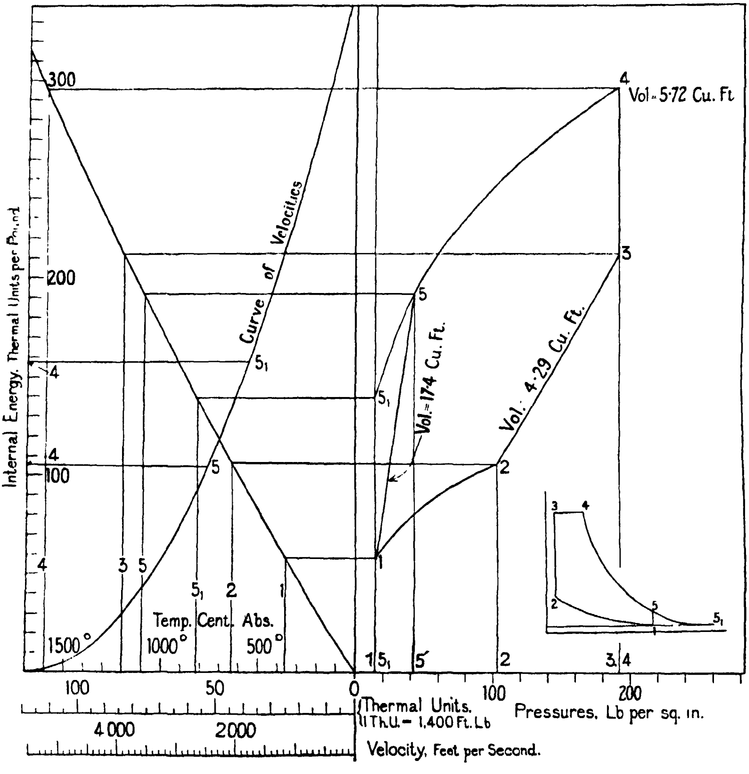
The change of internal energy, the vertical height 2 to 7, is 142 units; the work done at the constant pressure is 50 thermal units, making a total heat addition of 192 thermal units.

Adiabatic expansion to the original volume gives point 8 (at which the pressure is 37 lb. per square inch and the temperature of 860° absolute or 587° C.). The heat rejected is the height 1 to 8, being 92 thermal units, and the work done is 100 thermal units; the efficiency is 52·1 per cent. The mean pressure is $\frac{100 \times 1,400}{15 \cdot 7}$, or 8,920 lb. per square foot, that is, 62 lb. per square inch.

The work done during the expansion is the height 7 to 8, or 149 thermal units. Complete expansion gives point 8_1, or a temperature of 680° absolute, that is, 407° C.

The heat rejected in the form of internal energy is 56 thermal units, while the work done under constant pressure is 22, or a total of 78 thermal units; the work done is 114 thermal units and the efficiency 59·3 per cent. The velocity corresponding to point 8_1 is 4,080 feet per second, and that of point 8 is 3,660.

FIG. 6.—*Gas-Engine Cycle.*



In the fourth example, a maximum temperature 1,820° is reached, point 9, the volume being 3·48 cubic feet. The change of internal energy is 186 thermal units, while the work done under constant pressure is 64 thermal units, making a total of 250 thermal units added.

Adiabatic expansion gives point 10, an exhaust pressure of 44 lb. per square inch and a temperature of 1,060° absolute or 787° C.; the heat rejected is 126 thermal units, so that the work done is 124 thermal units and the efficiency 49·6 per cent.

The mean pressure is $\frac{124 \times 1,400}{15 \cdot 7}$, or 11,050 lb. per square foot, that is, 76·7 lb. per square inch.

The work done under the expansion, the height (9 to 10), is 159 thermal units. Complete expansion to the back pressure gives a temperature of 790° absolute or 517° C.; the heat rejected is 75 from the internal energy and 30 as work done during the constant pressure, making a total of 105 thermal units, the work done being 145 thermal units, giving an efficiency of 58 per cent. The velocity of discharge corresponding to point 10_1 is 4,340 feet per second, while that corresponding to 10 is 3,800.

In Fig. 6 is an example in which the heat is added partly at constant volume and partly at constant pressure, which is the case in an actual gas-engine. The given initial conditions are: pressure 1 atmosphere, absolute temperature 360°; the compression ratio is 5·45, the temperature at the end of heat addition at constant volume is 1,200° absolute, and at the end of constant pressure is 1,600° absolute. Drawing an adiabatic curve through the initial point until the given volume is reached at point 2, which is the end of compression, the pressure being 104 lb. per square inch, the temperature 640° absolute or 367° C., the work done in compression is the vertical height 1 to 2, or 48 thermal units; the volume at point 2 is 4·29 cubic feet. Heat is now added at constant volume until the temperature 1,200° is reached at point 3, the pressure being 194, and the heat added is 106 thermal units; from 3 to 4 heat is added at constant pressure until the maximum temperature is reached; the change of internal energy is 84 thermal units, while the work done under constant pressure is 28·5 thermal units; thus the [illegible] heat addition is

218·5 thermal units; adiabatic expansion takes place until the original volume of 17·4 cubic feet is reached, giving point 5, at which the pressure is 43 lb. per square inch, temperature 1,100° absolute or 827° C.; the heat rejected to exhaust is 134 thermal units, the work done being 84·5 thermal units and the efficiency 38·7 per cent.

The work done under the expansion is the vertical distance 4 to 5, or 104 thermal units.

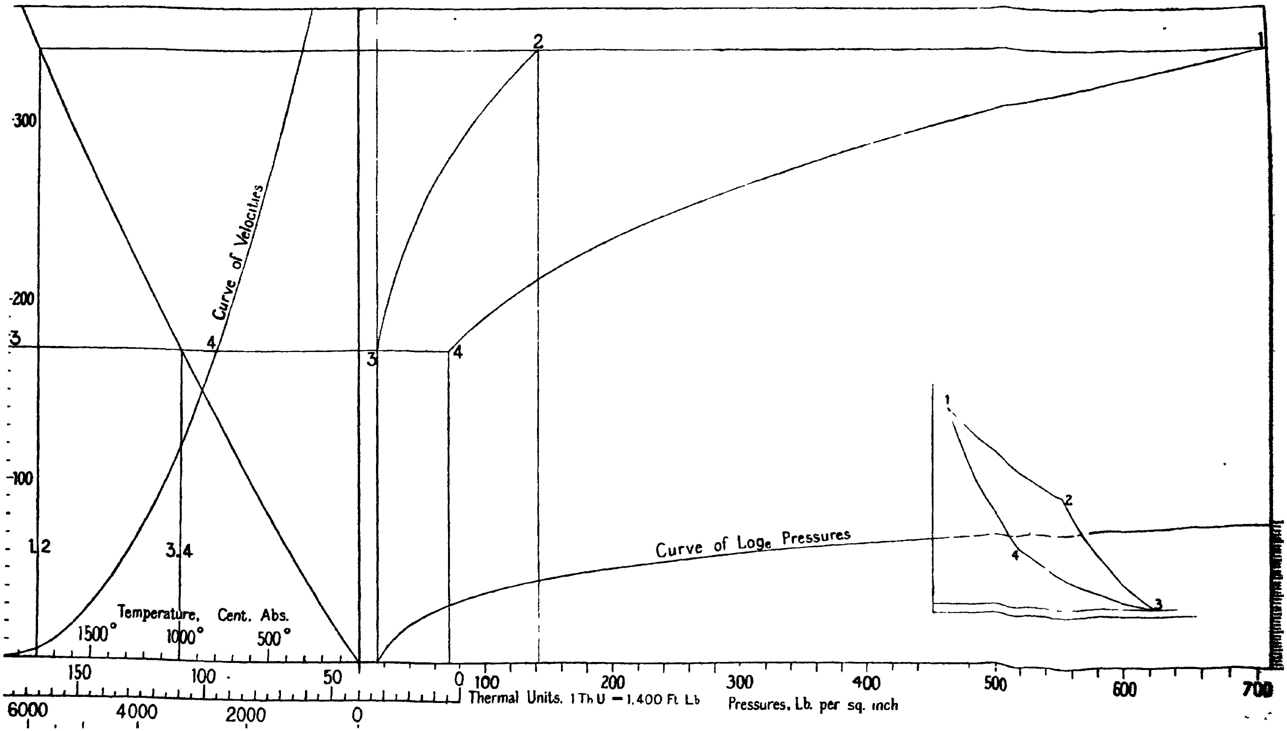
The cylinder volume is 17·4 — 4·29, or 13·11 cubic feet; so that the mean pressure $= \frac{845 \times 1,400}{13 \cdot 11}$, or 9,020 lb. per square foot and 62·7 lb. per square inch. Had the expansion been continued to atmospheric pressure at 5_1 the temperature would have been 820° absolute or 547° C.; the heat rejected in internal energy is 81 thermal units, and as work under constant pressure 32 thermal units, making a total of 113 thermal units, the work done being 105·5 units, the efficiency 48·2 per cent.

In Fig. 7 a Carnot cycle is shown with a lower temperature of 1,000° absolute, the upper temperature being 1,800° absolute, the maximum pressure 710 lb. per square inch, minimum pressure 1 atmosphere, the ratio of isothermal compression 5. The change of internal energy on compression and expansion is the vertical height of the diagram, which is 166 thermal units.

The heat added being at constant temperature and equal to $RT \log_e \frac{p_1}{p_2}$, the value of the first portion is 127 thermal units. The value of the logarithm is obtained from the scale of Napierian logarithms and amounts to 1·6; thus the total heat added is 203 thermal units. The heat rejected is obtained in the same manner, being 112, the work done 91 thermal units, and the efficiency 45 per cent. The cylinder volume is 47·3 — 1·74, or 45·5 cubic feet; the mean pressure is 2,800 lb. per square foot, and 19·45 lb. per square inch.

In the Stirling cycle, Fig. 8 (page 192), the heat is added at constant volume, while both expansion and compression are isothermal; the same temperatures are taken as in the Carnot cycle; the reduction in the maximum pressure is shown by inspection, and also the possibility of the use of a regenerator to take up the heat added

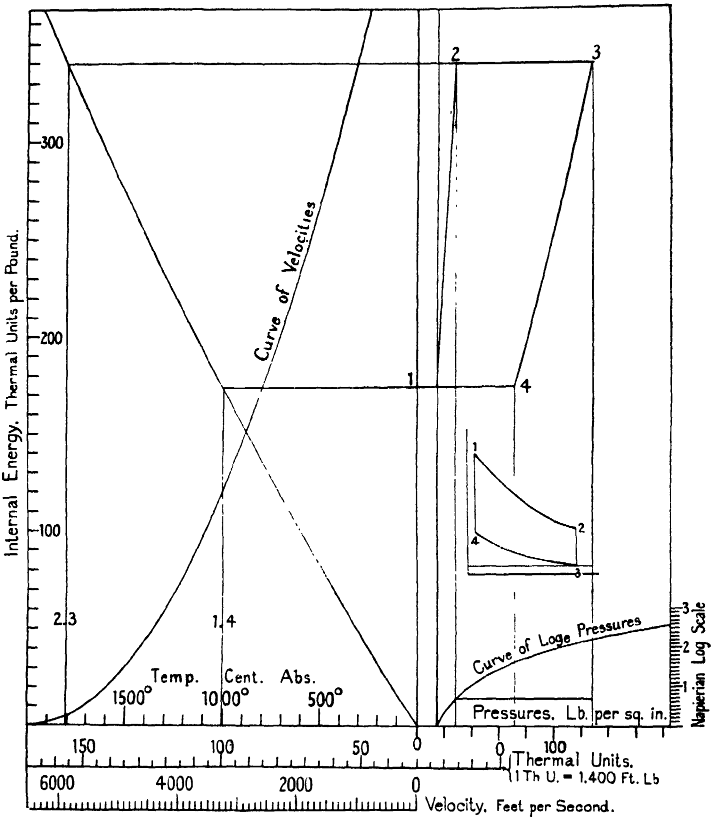
FIG. 7.—*Carnot Cycle.*



and rejected at constant volume, which in this case is 165 thermal units. The heat added at maximum temperature is 190·5 thermal units, making a total heat addition of 355·5 thermal units.

The heat rejected at the lower temperature of 1,000° absolute

FIG. 8.—*Stirling Cycle.*

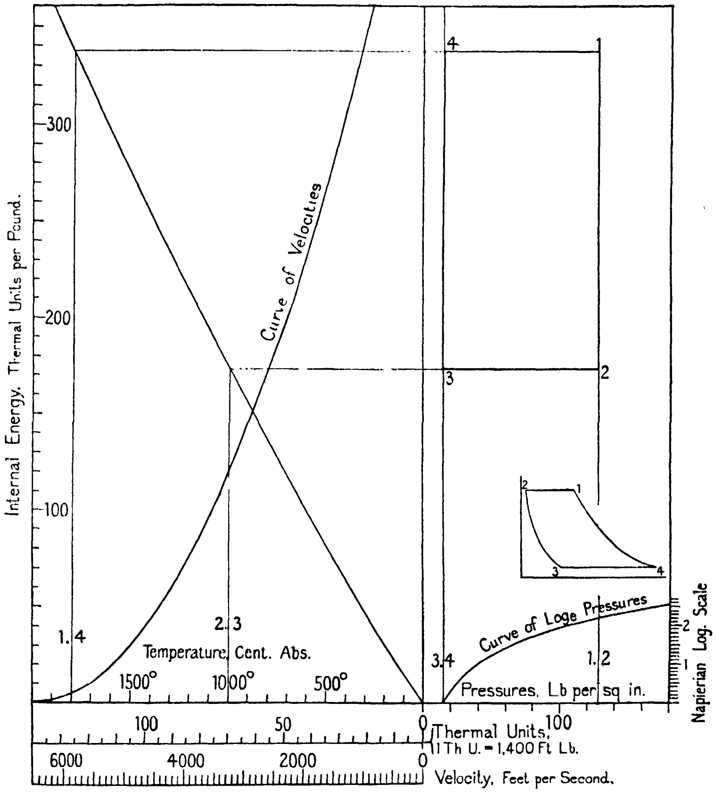


is 63 thermal units, making a total heat rejection of 228 thermal units; the work done is 127·5 thermal units, the efficiency being 36 per cent. without a regenerator.

The cylinder volume is 47·3 – 9·65, or 37·65 cubic feet, the mean pressure 4,750 lb. per square foot and 33 lb. per square inch.

In Fig. 9 is shown the Ericsson cycle, which consists of two isothermal and two constant-pressure lines, forming a rectangle on the energy-diagram, and showing that a regenerator can be employed to store up the heat added and rejected at constant

FIG. 9.—*Ericsson Cycle.*



pressure. The temperature limits are the same as before, the maximum and minimum pressures being 125 and 15 lb. per square inch respectively.

The heat added at constant temperature between 1 and 4 is 280 thermal units. The change of internal energy at constant pressure is 165 thermal units, while the work done is 56 thermal units, making a total heat addition at constant pressure of 221 thermal units.

The heat rejected at the lower temperature is 154 thermal units; the change of internal energy and the work done are the same at the lower as at the higher pressure. The total heat added is 501 thermal units; the heat rejected is 375, the work done being 126 thermal units, and the efficiency 25·1 per cent. when a regenerator is not used.

The cylinder volume is 46·8 – 9·65, or 37·15 cubic feet, the mean pressure being 4,750 lb. per square foot, or 33 lb. per square inch.

The author desires to thank Mr. F. J. Broscomb, B.Sc., for his assistance in the laborious computations and in the construction of the diagram.

The Paper is illustrated by 9 Figs. in the letterpress.

MEMOIRS.

George William Appleby was born at Newcastle-on-Tyne on 24th June 1860. He was educated at Westport House School, Great Grimsby, and served his apprenticeship from 1875 to 1881 in the works of Messrs. John Abbot and Co., at Gateshead. As chief engineer he served in the mercantile marine, and with Messrs. R. and W. Hawthorn and Co., and Sir W. G. Armstrong and Co., in the ordnance works and shipyard. In 1887 he went to China as engineer of one of the Chinese gunboats for Messrs. Armstrong and Co., and soon after the taking over of the vessel by the Chinese Government he joined the Coast Staff of the Imperial Maritime Chinese Customs as second engineer. In 1895 he was promoted to be first engineer of the revenue cruiser "Likin." Subsequently he was engaged in surveying and superintending the docking and repairs to the Customs and Chinese cruising launches stationed in South China. In 1890 he had conferred upon him the Order of the Pao Hsing (4th class) in recognition of the services he rendered. His death took place at Shanghai on 29th August 1910, at the age of fifty. He became a Member of this Institution in 1899.

Dr. Harold Thomas Ashton was born at Darwen on 21st April 1867. He was educated at Owens College, Manchester, where he gained the Fairbairn prize and first-class awards in engineering, applied mathematics, etc., together with honours in the Bachelor of Science degree. This was followed by his obtaining the Master of Science degree in 1889, and that of Doctor of Science in 1900. His apprenticeship of over four years was served at Messrs. W. and J. Yates' Canal Foundry in Blackburn. On the recommendation of Professor Osborne Reynolds, of Victoria University, Manchester, he was appointed, in 1890, mechanical assistant to the superintendent of the Royal Laboratory, Woolwich Arsenal, and this position he held for over nine years. In 1899 he was promoted to be assistant mechanical engineer under the chief mechanical engineer, which was followed in 1905 by his appointment as superintendent of the Royal Small Arms Factory at Enfield Lock. During the tenure of this position he read a Paper at this Institution on "The Manufacture and Upkeep of Milling Cutters."* In 1908 his health became impaired and for the last two years of his life he was an invalid. His death took place on 22nd December 1910, in his forty-fourth year. He became a Member of this Institution in 1902; he was also a Member of the Institution of Civil Engineers.

THOMAS JOHNSON BRITTEN was born in Herefordshire in 1858, and was educated at Doncaster Grammar School. In 1887 he went to the Transvaal as representative of Messrs. R. Hornsby and Sons, of Grantham, and erected a large number of first-reduction plants on the Rand. From 1889 to 1893 he practised as a consulting engineer in Johannesburg, and then was appointed general manager of the Wolhuter Gold Mines. This position he held until 1905, when he became consulting engineer to Sir Abe Bailey, K.C.M.G., the development of whose interests in Rhodesia he watched during the last few years of his life. In 1902 he invented and brought out an atomizer for laying or settling the dust or pulverized rock created in the boring and blasting of holes, and soon afterwards he gained the £500 prize and gold medal given by the Transvaal Chamber of Mines, and open to the world, for the best means of preventing miners' phthisis. His death took place at Johannesburg on 24th October 1910, at the age of fifty-two. He became a Member of this Institution in 1895.

GEORGE COCHRANE was born at the Lower Ward, Windsor Castle, on 9th May 1851, and was educated at Clewer House School, Windsor. In 1867 he began an apprenticeship at the Britannia

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* Proceedings, I. Mech. E., 1907, Part 4, p. 1021.

Works, Birkenhead, and on its completion in 1872 he became draughtsman at the works of the Hydraulic Engineering Co., Chester. Subsequently he was promoted to be chief draughtsman, and then works manager. In 1879 he left to take the appointment of works manager to Messrs. Ross and Walpole, North Wall Foundry and Ironworks, Dublin, and this position he held until 1883, when he was appointed Resident Engineer and subsequently Superintendent Engineer to the London Hydraulic Power Co. He remained in this position until his death, which took place in Camberwell on 4th March 1911, in his sixtieth year. He became a Member of this Institution in 1887.

WILLIAM DAVIDSON was born at Inverurie, Aberdeenshire, on 3rd October 1867. He was educated at Robert Gordon's College, Aberdeen, from 1880 to 1887, and during the latter part of the time he served an apprenticeship in the works of Messrs. W. Rae and Sons, of Inverurie, and of Messrs. W. McKinnon and Co., of Aberdeen. In July 1887 he entered the works of Messrs. Dübs and Co., of Glasgow, and remained there until 1890, when he was engaged in the locomotive works of the Great North of Scotland Railway. In 1892 he went to India and was appointed assistant locomotive superintendent on the Bombay, Baroda, and Central India Railway. He was made a district locomotive superintendent in 1896, and officiated as deputy locomotive superintendent in January 1904. He acted as locomotive and carriage superintendent on the same railway during 1907, and on the Rajputana Malwa Railway, in 1908, in the same capacity. In 1910, on his return from leave, he took up the officiating appointment of locomotive and carriage superintendent on the Bombay, Baroda, and Central India Railway, and it was while holding this appointment that his death took place on 1st July 1910, in his forty-third year. He was a keen volunteer and excellent rifle shot, being well known in northern meetings in India. He received the Volunteer Officers' Decoration in 1907. He became a Member of this Institution in 1904.

WILLIAM HORATIO HARFIELD was born in London on 13th May 1832, and was educated at King's College, London. After serving his apprenticeship he entered the office of his stepfather, Thomas Brown, and was subsequently taken into partnership, which constituted the firm of Brown and Harfield, the original inventors of the modern system of working cables for anchors, now universally adopted both in war and in merchant vessels. As junior partner of Brown and Harfield he saw this system adopted for the "Great Eastern" in 1857, and, as principal of Harfield and Co., for the largest of modern warships, the Dreadnought cruisers "Lion" and "Princess Royal." In 1889 the question of improving the system of steering gear engaged his attention, and he invented a simple and most effective type of compensating steering gear, consisting essentially of an eccentric pinion working in a corresponding rack connected to the rudder post, so arranged that increased leverage was obtained as the rudder strains increased, thus enabling the rudder to be moved rapidly when the strains were light, and to be put hard over with smaller engines and with less steam consumption than were required with the old type of gear. This compensating gear was adopted with great success in British and foreign war vessels of all classes. Notwithstanding his business activities he greatly interested himself in the auxiliary forces, having been for several years lieutenant-colonel of the Middlesex Yeomanry, which he brought to a high state of efficiency before resigning. He was D.L. and J.P. for the county of Middlesex. He died at his residence, Sunbury Court, Middlesex, on 24th September 1910, at the age of seventy-eight. He became a Member of this Institution in 1869.

CHARLES ARBUTHNOT HUBBACK was born at Heath End, near Aldershot, on 29th July 1867. He served his apprenticeship in the works of the North London Railway at Bow, under Mr. J. C. Park, and of the Taff Vale Railway, Cardiff, as a fitter and afterwards draughtsman, under Mr. T. Hurry Riches. He then went abroad, having been appointed locomotive superintendent of the Tehuantepec Railway, Mexico, and on the completion of his three years' agreement he went in the same capacity on the Natal and Nova Cruz Brazilian Railway. On the termination of the agreement he became locomotive superintendent on the Lagos Government Railway, West Africa, but had to resign his post after a few months on account of his health breaking down. On recovering his health he proceeded to Chile as locomotive superintendent on the Nitrate Railways, Iquique, and after he had completed his three years' agreement he returned to England. In June 1910 he went to Vancouver, British Columbia, and there he was employed on construction work for the Canadian Pacific Railway in the Rocky Mountains. Owing to the severity of the weather he contracted an illness which resulted in his death at Vancouver on 25th January 1911, at the age of forty-three. He became a Member of this Institution in 1891.

WILFRED LANDSTEIN was born in Glasgow on 18th January 1875. Five years later his parents removed to Liverpool, and at the Liverpool Institute he received his education. In 1889 he commenced his apprenticeship in the North Mersey Engine Works at Bootle, Liverpool, and on its completion in 1894 he spent a brief time in the works of Messrs. Rollo and Sons, of Bootle. In June 1895 he joined Messrs. Holt's Ocean Steamship Co., and went direct to Singapore, where he served and graduated until he returned to England in 1898 to obtain his chief engineer's certificate. He then cruised with Lord Newborough as chief engineer of his steam yacht "Fedora." In March 1900 he rejoined the Ocean Steamship Co., and in June 1901 he was appointed chief engineer of one of their steamers. Subsequently he had supervision of the same company's wharf, pontoons, and property at Deli, Sumatra. In 1909 he was invalided home suffering from a severe breakdown, from the effects of which he did not seem to recover. However, after six months' rest, he returned to Singapore, but had not been there very long before he finally returned, the effects of malaria and sunstroke proving fatal. His death took place at Mossley Hill, Liverpool, on 12th January 1911, shortly before his thirty-sixth birthday. He became an Associate Member of this Institution in 1907.

Victor Albert Hill McCowen was born at Tralee, Ireland, on 15th December 1865, and received his early education locally. At the age of sixteen he entered the engineering works of Messrs. McCowen and Sons, Tralee, as draughtsman and assistant engineer, superintending the erection of mill machinery, engines, etc. From 1888 to 1891 he studied at the Finsbury Technical College, London, and then became assistant engineer on the staff of the late Messrs. J. E. H. Gordon and Co., of Pall Mall, London, electrical engineers, being employed in the designing and estimating department. In 1892 he was in charge of the mains to the Electrical Exhibition at the Crystal Palace, and for a short time he was engineer-in-charge at the Sydenham District Electric Supply Station, and subsequently was one of the superintending engineers on the Bray electric lighting scheme. From 1892 to 1894 he acted as chief engineer to the Killarney Electric Light Co., and designed and carried out the scheme, including the construction of water-races, erection of turbines and electric machinery, etc. In 1894 he was appointed City Electrical Engineer to the Belfast Corporation, and superintended the erection of Professor (now Sir Alexander) Kennedy's gas-engine scheme, on which subject he read a Paper * at the Summer Meeting of this Institution in Belfast. Subsequently he designed and carried out the erection of a large steam-driven generating station for the supply of power and light at Belfast. He also carried out the electrification of the Belfast City tramways, including the overhead equipment, underground feeder system, and the generating station. In 1907 he was appointed Borough Electrical Engineer for Salford, which position he held until August 1910. His death took place at Bath on 8th September 1910, in his forty-fifth year. He became a Member of this Institution in 1898; he was also a Member of the Institution of Electrical Engineers.

Charles Hill Morgan was born at Rochester, N.Y., on 8th January 1831. His parents were of New England stock, the line of his father going back to Miles Morgan, one of the founders of

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* Proceedings 1896, Part 3, page 304.

Springfield, Mass., who went from Bristol to America in 1636. His father having been a mechanic of limited means, the son Charles was obliged to work in a factory at the age of twelve, and his early education was that afforded by the Massachusetts district school of seventy years ago, and short terms in the Lancaster Academy. At the age of fifteen he entered the machine shop of his uncle, as an apprentice. At seventeen he determined to learn mechanical drawing, and through his efforts a class for the study of this subject was formed. Those few lessons in drawing, taken at night, after twelve hours' work in the shop, were the most important factor in establishing his mechanical career. In 1852 he was put in charge of the Clinton Mills dye-house, and he devoted himself to the study of chemistry. For a time he was draughtsman in the works of the Lawrence Machine Co. Later, from 1855 to 1860, he was mechanical draughtsman for the distinguished inventor and manufacturer, Erastus B. Bigelow. Forming a partnership in 1860 with his brother, Francis H. Morgan, he was for several years engaged in the manufacture of paper bags in Philadelphia, and during part of this time a paper mill was operated by the firm near Coatesville, Pa. In 1864 he was appointed superintendent of manufacturing for the firm of I. Washburn and Moen, wire-manufacturers, of Worcester, Mass. Four years later, when the concern was converted into a company, he became general superintendent. He made many trips to Europe for the purpose of visiting the various wire-mills and of keeping himself informed of the changes and improvements adopted. He was for eleven years one of the directors of the company.

Mr. Morgan has been most prominently identified with the development of the continuous rolling mill. The first continuous mill was designed and originally constructed by Mr. George Bedson, in Manchester, England. One of these was purchased by his firm and erected in Worcester, Mass., in 1869, and constituted a great advance over the rolling previously practised. It soon became evident that the means of handling the product of the mill were inadequate, and the first important step in the development was the power-reel designed by Mr. Morgan. He then added a continuous train of horizontal rolls, which was followed in 1886 by the invention of automatic reels, both of the pouring and laying types. In 1887 declining health led him to resign his position as general superintendent of the Washburn and Moen Manufacturing Co. Some years before, in 1881, he had founded the Morgan Spring Co., and in 1891 he founded the Morgan Construction Co., of Worcester, Mass., manufacturers of rolling mill and wire-drawing machinery. In 1893 he served on the Board of Judges of the World's Exposition in Chicago, and in 1900 the U.S. Navy Department nominated him one of a committee of three distinguished engineers to report upon the merits of special gun-lathes. In December 1899 he was elected President of the American Society of Mechanical Engineers, and in that capacity took part in the Joint Meeting* with the Institution of Mechanical Engineers in London. On this visit he was received in audience by three Sovereigns—Queen Victoria, King Oscar of Sweden, and King Leopold II. of Belgium. He was always an admirer of Henry Cort, the inventor of the art of puddling iron with coal and of rolling metals in grooved rolls, and in 1905 he had two bronze tablets erected in memory of Cort, one of which he presented to Lancaster, Cort's birthplace, and the other to the church at Hampstead where he was buried.† Mr. Morgan's death took place at Worcester, Mass., on 10th January 1911, at the age of eighty. He became a Member of this Institution in 1900; he was also a Member of the American Society of Mechanical Engineers, the American Institute of Mining Engineers, the Iron and Steel Institute, and an Honorary Member of the Société des Ingénieurs Civils de France.

JOHN WYLIE NISBET was born in Edinburgh on 20th May 1868. His early education was received at Blairlodge Academy, Polmont, Stirlingshire, and his technical education at Falkirk and the Andersonian College, Glasgow. In 1883 he began his apprenticeship of five years with Messrs. J. T. Salveren and Co. at their Redding

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* Proceedings 1900, Part 3, page 353.

† *See* Remarks by Mr. J. Hartley Wicksteed on the Presidential Address by Mr. Edward P. Martin, Proceedings 1905, Part 2, p. 363.

Colliery Works, Stirlingshire, of which his father was chief mechanical engineer for many years. On its completion in 1888 he was engaged for three years in the locomotive department of the North British Railway, Cowlairs, Glasgow, and from 1891 to 1895 he was employed by Messrs. Lucas and Aird on the construction of the West Highland Railway, where he superintended the building of plant, erecting bridges, cylinder-sinking, etc. On the completion of the West Highland Railway he was engaged for one year on the Budleigh Salterton Railway, South Devon, and then in 1896 he went as assistant engineer for Messrs. John Aird and Co. on the construction of the Holsworthy and Bude Railway, North Devon. On the completion of this work he was appointed by the late Sir John Aird to superintend the construction of new gas-works at Nechells * for the Birmingham Corporation.

In 1900 he returned to London and was appointed works manager for Messrs. Aird and Sons at Belvedere Road, Lambeth, which post he held until his death. During the period he was in London he had charge of many other works, notably the erection of piers on the River Thames for the London County Council, the building of a new wharf for the Gas Light and Coke Co. at Deptford, the timbering, shoring, and clearing of the roof of Charing Cross Station after the collapse that took place. His death took place in London on 17th February 1911, in his forty-third year. He became a Member of this Institution in 1909; he was also Chairman of the Junior Institution of Engineers at the time of his death.

JOHN RUFFELL SALTER was born in London on 11th April 1875, and was educated at Sir Walter St. John's School, Clapham, and subsequently under Professor E. Wilson, of King's College, London. In 1893 he became junior assistant to the late Dr. John Hopkinson, Member of Council of this Institution. Shortly after Dr. Hopkinson's death in 1898 he became chief assistant engineer to Sir Clifton Robinson, and was responsible under him for the electrical

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* These Works were visited at the Birmingham Summer Meeting in 1910, and are described in the Proceedings 1910, Part 3, page 1320.

construction and equipment of the London United Tramways and the Bristol Tramways. During this period he also acted as consulting engineer to the Pemberton Urban District Council in designing and erecting their generating station for electric lighting and tramways. In March 1902 he was appointed engineer-in-chief of the South Lancashire Tramways Co., and was responsible for the construction and equipment of about 100 miles of tramways. On the completion of the constructional work he became general manager of the company, and in 1903 he was appointed to the position of general manager of the St. Helens tramways in order to secure centralization of management of the two systems, requiring through-running arrangements over both systems and into Liverpool. He acted as consulting engineer to the Birkenhead and Chester Light Railway scheme, and to the Heywood Corporation in connection with the conversion of the steam-tramway system to electrical working. On several occasions he went abroad to give expert advice on tramway undertakings. His death took place at his residence at Worsley, Manchester, as the result of an operation rendered necessary by an acute attack of pneumonia, on 16th December 1910, in his thirty-sixth year. He became an Associate Member of this Institution in 1903.

Sir WALTER SCOTT, Bart., was born at Abbey Town, West Cumberland, on 17th August 1826. His parents were in humble circumstances, and the education that was given to him was exceedingly meagre. He started working very early, as a mason, and on completing his apprenticeship he was employed on the construction of railways in the north of England. In 1846 he acted as foreman on the Gretna Green section of the Caledonian Railway, and two years later he went to Newcastle-on-Tyne and was employed on the building of the Central Station and of the North Eastern line to Berwick. Here he settled down and, commencing business on his own account as a contractor, speedily became one of the foremost men in the district. He erected or embellished many of the most important buildings in the neighbourhood, notably, the restoration of Newcastle Cathedral, under Sir Gilbert Scott, the extension of the Elswick Works, additions to Chillingham Castle, and the rebuilding of Haggerstone Castle. In 1867 he began his railway work, this being the branch of the North Eastern Railway to the quayside at Newcastle, and since that time he had rarely been without work for the extension of the North Eastern Railway, its branches and docks. In 1882 the firm became Messrs. Walter Scott and Co., by the admission of his son, Mr. John Scott, and Mr. J. T. Middleton, his engineer and agent, and large undertakings were carried out by them in all parts of the kingdom. These included the construction of extensive reservoirs for the Stockton and Middlesbrough Water Board, railways for the Great Eastern Railway Co., including the "Essex" lines to Southend-on-Sea, Maldon, and Burnham-on-Crouch. The firm were the pioneers in the construction of electric railways in London, having built the first section of the City and South London Railway. They also completed an important section of the Central London Railway, extending from the Marble Arch to the General Post Office.

Sir Walter Scott's publishing works at Felling, Co. Durham, are world-famous, and as a publisher of the "Canterbury Poets," the "Camelot Classics," translations of Ibsen's and Tolstoy's works, his name is a household word. At the works at Felling everything in the production of a book was undertaken, except the manufacture of the raw material. He was also Chairman of the Leeds Steel Works, Leeds, Chairman of Messrs. Smith, Patterson and Co., engineers and ironfounders, Blaydon-on-Tyne, and he was proprietor of several collieries and director of many large industrial concerns. For some years he was a Member of the Newcastle City Council. In recognition of his great works, a Baronetcy was conferred upon him by the King in 1907. Latterly he had been in indifferent health, and went to the South of France in January 1910 in the hope that he might benefit by the change. His health, however, became worse, and his death took place at Mentone on 8th April 1910, in his eighty-fourth year. He became an Associate of this Institution in 1887.

HENRY HAY WAKE was born in Sunderland on 2nd January 1844, and in 1860 entered, as a pupil, the service of Mr. Thomas Meik, who was at that time engineer to the River Wear Commissioners. In 1868, at the comparatively early age of twenty-five, he was appointed engineer to the said Commissioners upon the retirement of Mr. Meik, and he therefore remained practically the whole of his lifetime in the service of the River Wear Commission. An idea of the extent of the work under Mr. Wake's control may be gathered from the fact that the jurisdiction of the Commission covers the tidal part of the river, a dock estate of 250 acres, and a stretch of coast along the North Sea. The Roker Harbour Works were built to his designs and under his personal superintendence and were completed in 1903; they form the defence to the entrance to the River Wear. The two piers forming the harbour extend to a length of about 2,800 feet each, and enclose about 125 acres of water at high water. These works were visited by the Members of this Institution on the occasion of the Summer Meeting in Newcastle-on-Tyne in 1902, and all who took part in that visit will have pleasant recollections of their reception by the River Wear Commissioners and of the admirable arrangements made by Mr. Wake to enable them to examine the operations in progress.* He drew up the plans for providing Sunderland with a complete system of wet and graving docks, including the installation of coal staiths and a complete set of warehouses. In 1907 he retired to take up the position of consulting engineer to the same Commission, a post which he retained until his death. He was a recognized expert in harbour work, and acted as consulting engineer for several other corporations and public bodies; in this connection he contributed largely to the development of Seaham Harbour. Of late years his health had been failing, and his death took place at his residence in Sunderland on 17th February 1911, at the age of sixty-seven. He became a Member of this Institution in 1881; he was also a Member of the Institution of Civil Engineers.

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* Proceedings, I. Mech. E., 1902, Part 3, page 580.

Thomas Walpole was born at Kingstown, near Dublin, on 19th March 1834, being the son of the late Edward Walpole—a name well known in connection with the linen industry of Ireland. In early life, developing mechanical abilities, he was placed under his uncle, Mr. Albert White, in the Waterford shipbuilding yard, where for several years he worked assiduously on the design and construction of yachting and mercantile vessels. Later, he removed to Dublin, where his firm—Ross and Walpole—formed an extensive connection in shipbuilding and engineering projects. Latterly he retired from professional life. His death took place at his residence in Monkstown, Co. Dublin, on 5th January 1911, in his seventy-seventh year. He became a Member of this Institution in 1865.

The Institution of Mechanical Engineers.

PROCEEDINGS.

MARCH 1911.

An ORDINARY GENERAL MEETING was held at the Institution on Thursday, 16th March 1911, at Eight o'clock p.m.; EDWARD B. ELLINGTON, Esq., President, in the chair.

The Minutes of the previous Meeting were read and confirmed.

The PRESIDENT announced that the Ballot Lists for the election of New Members had been opened by a Committee appointed by the Council, and the following eighty-two candidates were found to be duly elected:—

MEMBERS.

AULD, JOHN,	Barry.
BATEMAN, HENRY HERBERT,	Rangoon.
BATES, WALTER JAMES,	Manchester.
CAMERON, ARCHIBALD PRESTON,	Calcutta.
COOPER, STANLEY,	Birmingham.
DONKIN, SYDNEY BRYAN,	London.
HEAP, WILLIAM,	Colombo.
JUDD, WILLIAM WARNER,	Colchester.
KANTHACK, FRANCIS EDGAR,	Pretoria.
LAMB, FRANCIS STEWART,	Wallington.
LANE, Major FREDERICK, A.O.D.,	Edinburgh.

Nicol, George Andrew,	Hull.
Rowland, William,	Manchester.
Walker, Kennedy,	London.
Watson, Cecil,	London.

ASSOCIATE MEMBERS.

Beanland, Henry,	Garnant, Carmarthen.
Bill, Charles Edward Stewart,	Birmingham.
Bowen, William,	Cambridge.
Bulleid, Oliver Vaughan Pugh,	London.
Chance, Clinton Frederick,	Birmingham.
Coates, Frederick,	London.
Cowan, John,	Calcutta.
Davison, William,	Liverpool.
Green, George Alan,	Brussels.
Hall, James Cochar,	Durban.
Holliday, Thomas,	London.
Inchley, William,	Nottingham.
James, David,	London.
Jones, Alfred James,	Peterborough.
Kay, John Duncanson,	Victoria, B.C.
Lightfoot, Kenneth,	London.
Mathews, Patrick Edward,	Dublin.
McKay, Robert Ferrier,	London.
Murray, Herbert Howard,	East London, C.C.
Nicol, William Alexander Wooler,	Auckland, N.Z.
Omar, Abdel Mageed,	Leeds.
Orme, Charles Temple,	Coventry.
Pepper, Walter Reeve,	Calcutta.
Perry, Frederick Buckland,	Lincoln.
Reeve, Edward,	Birmingham.
Reid, Robert Whyte,	Derby.
Riley, Henry Percival,	Cuba.
Robertson, George Patrick,	Darjeeling.
Rose, Percy Thomas,	Rishra, Bengal.

Schwenk, Frederick Louis,	Kulti, Bengal.
Smedley, Frederick Thomas,	London.
Stanford, Eric Spencer,	London.
Ticehurst, John William,	London.
Tsuda, Goichi,	London.
White, John Duncan,	Wolverhampton.
Whittington, Richard Henry,	Kilmarnock.
Whitworth, Leonard,	Manchester.
Williams, Charles Thomas,	Wakefield.

GRADUATES.

Armstrong, Stanley,	Workington.
Beattie, Stuart Nivison,	London.
Beit, Rupert Owen,	Darlington.
Bevan, Parker Samuel,	Glasgow.
Birch, Ernest William,	London.
Copley, Hugh,.	Birmingham.
Crawshaw, Percy William,	Lucknow.
Crowfoot, Arthur Rustat,	London.
Frew, David Benny,	Edinburgh.
Haile, Edward,	Brighton.
Heap, George Herbert,	Lincoln.
Homewood, James Blüm,	Gravesend.
Johnson, Arthur,	Birmingham.
Jones, George Bishop,	Chester.
Knight, Roy Engleheart,	London.
Laity, William Harvey,	Camborne.
Lapworth, Francis James,	London.
Leigh, Harold,	London.
Marsh, Ernest Huram,	Grantham.
Prichard, Lewis,	London.
Russel, John,	Maidstone.
Salmon, Maurice William,	Reading.
Simpson, Alfred Henry,	London.
Theakston, Francis,	London.
Trenfield, Ernest John,	Liverpool.

Webb, Harold,	London.
Willcox, Christopher Watson,	Birmingham.
Wray, George Henry,	Leeds.
Young, Thomas Kenneth,	Beckenham.

The President announced that the following thirteen Transferences had been made by the Council:—

Associate Members to Members.

Drummond, George Richard,	Rajputana.
Elton, Sydney George,	Calcutta.
Gobey, Francis Edward,	Manchester.
Harold, Harold Francis, Eng.-Lieut., R.N.,	H.M.S. "Victorious."
Haslam, Sidney Bertram,	Cardiff.
Hawkins, Eustace Fellowes,	Sévran.
Hemmings, Henry Francis Lewis,	Rugby.
Jenkin, Charles James,	London.
Lewis, Fredrick William,	Lincoln.
Potter, Henry Samuel,	Johannesburg.
Prestwich, John Alfred,	London.
Robertson, George Findlay,	Bessbrook.
Shave, George James,	London.

The President then delivered his Inaugural Address.

The Meeting terminated at a Quarter past Nine o'clock. The attendance was 151 Members and 35 Visitors.

ADDRESS BY THE PRESIDENT,

EDWARD B. ELLINGTON, Esq.

The main considerations in selecting a subject for the customary Address of your President should be to appeal to the greatest number of the members, and if possible to secure some permanent value to the Institution. In these days of encyclopædic knowledge and its application, there is manifest failure before me if I attempt to give you anything in the nature of a general résumé of the progress of engineering science during the period with which I have had personal acquaintance with the subject. Such an Address could no doubt be made interesting by some authors and serve to pass an hour's time in the comforting contemplation of the marvellous progress of the mechanism of life, but I doubt whether it would prove of the slightest value to anyone, and I am sure if I myself attempt it I shall only bore you.

An alternative before me was to address you on the subject of the particular branch of engineering to which I attached myself some forty years ago, and to which I and a few of my compatriots have devoted ourselves ever since. I do not know what may be the fate of the distribution of hydraulic power in the future. It may be destined to occupy a permanent even if subordinate position amongst the various means which are available for the transmission of energy, or, as a friend of mine has humorously suggested, it may so completely pass into the limbo of forgotten industries as to not even find a place in the "Encyclopædia Britannica" when the next edition is forthcoming. This at any rate is clear, that hydraulic power itself, apart from a particular method of application, is, after the sun, the most lasting source of energy, and the most easily adapted to the wants of mankind of any of the great forces of Nature. I believe I could make an Address on my own subject interesting and useful, but I have decided against it. The fact is, that it would be impossible for me to deal adequately with it, without appearing as an advocate of a particular system. I have often, both in written and spoken words, succeeded, as I thought, in being strictly impartial and scientific, but I have found, almost invariably, that what I have said has been at once discounted as emanating from an advocate. I do not intend therefore, if I can help it, to do an injury to the Institution by laying your President open to that charge while occupying this Chair.

If I am to be debarred from addressing you on the subject of the general progress of Engineering, and also on the particular progress of the special branch of engineering about which I know most, it would seem that I should be without a text at all and have to wander on in a maze of small talk which would exhaust you and myself. However, there is a subject which should be of great interest to all of us, and, if my discourse should not prove of value, it will be due to the manner in which it is presented and not to the subject itself. I desire to direct your thoughts to Mechanical Engineering in general, and its relation to other branches of Engineering, also in particular to the purposes and objects of this Institution, and its relation to other Engineering Institutions.

Mechanical Engineering.—Owing to the great advance that has been made in the mechanical arts and especially in Engineering during the period since the Smeatonian Society was formed in 1771, it was inevitable that these great changes should be reflected in the associations of engineers formed to promote their common aim. Engineers have to know more and to be more completely trained than in the past. Their life has become more complicated and serious, and in the United Kingdom alone there are now over fifty Institutions and Societies which have to do with Engineering in one or other of its branches. Our Institution, as it is the oldest, claims also to be the most representative body of mechanical engineers in the country, but so far as I have been able to ascertain there is no definition of what exactly a mechanical engineer is, or exactly in what respect mechanical engineering constitutes a special branch of the profession.

I have placed upon the wall a drawing of possibly the oldest example of mechanical engineering work now extant. The drawing * has been prepared by Mr. James P. Maginnis, M.I.Mech.E., who has presented it to the Institution. It represents a bronze pump in the British Museum, found at Bolsena in Etruria, and attributed to Ctesibius, a barber of Alexandria, who lived in the Third Century B.C.† He was probably a contemporary of Archimedes, the inventor of a screw for raising water. Curiously enough, a pump constructed on the same principle as Ctesibius' was unearthed a few years ago during the excavations at Silchester, the old Romano-British city situated not far from Reading. This pump was a much cruder affair, made of wood and lead, but undoubtedly was an effective force-pump, and suggests that force-pumps were in considerable demand at the time of the Roman Empire. Indeed, there was an edict promulgated in Rome at this period, by which every citizen was required to keep a fire-engine of some sort in his house.‡ The dawn of Mechanical Engineering appears to have been heralded by machines for the pumping of water.

An early example of Mechanical Engineering in this country was the erection in 1582 of a pumping engine under the first arch of the old London Bridge, worked by water-wheels driven by the rise and fall of the tide.§ It is interesting to note that at this

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* *See* Paper by James P. Maginnis (page 309), and Plate 21.

† Smith's Classical Dictionary, p. 259. Ed. 1904.

‡ Ewbank's "Hydraulics and Mechanics," p. 311.

§ Smiles' "Brindley and the Early Engineers," p. 51.

period it was a Dutchman, Peter Morice, who executed the work, which again suggests the importance of water to the making of Mechanical Engineers.

Water-wheels, one would imagine, must have been in use from very early times, but evidence such as that of the ancient pump is wanting. Undoubtedly there was also machinery of some sort used in the building of the monumental works in Egypt and the East, and the ancient chariots exhibited no mean amount of mechanical skill. Nevertheless it is, I suppose, the fact that "could a man who lived in England but a hundred years ago now revisit his country he would in mechanical art find a change far greater than the whole progress from the creation to the time at which he lived." *

A curious fact in the history of development of Mechanical Engineering is that the priests of the ancient religions seem to have been acute mechanicians, and invented many contrivances for deluding the people—an art in which some of the mechanical engineers of the day are not wholly deficient.

While apparently there have been millwrights, mechanicians, and philosophical-instrument makers from early times, mechanical engineering as a profession is clearly of quite recent origin, and engineering organization starts with the Smeatonian Society. Next to the Smeatonian, which occupies a position of ease and content in a pleasant backwater of the present, the oldest and most comprehensive of Engineering Institutions is of course that of the Civil Engineers. Here there is more substantial ground on which to rest. Civil Engineers were differentiated from Military Engineers, and the latter when on the active list are not eligible for corporate membership of the Institution of Civil Engineers. The comprehensiveness of Tredgold's definition of Engineering is obvious. It may be taken to apply to the whole content of civilization, and engineering in fact emerged with the first dawn of civilization. Man, as has been well said, is a tool-making animal. The

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* Imray and Biggs' "Mechanical Engineering," p. 12.

first being who made a tool was the first engineer, and inaugurated unknown to himself the art of engineering. Such a reflection may be useful in making us realize the all-embracing character of engineering in connection with our life today, but is not otherwise very helpful in our actual circumstances. The Institution of Civil Engineers at its first inception in 1818, now nearly a century distant, realized its true function; while perhaps it can hardly be said that it has always acted up to its ideal, there has never been a time in its honoured career when it has not striven to maintain its character of the representative Institution of Engineering in this country and in the Empire at large. Today it is more than ever alive to its duties in this respect, and is doing all in its power to improve the status of Engineering. It admits to its privileges all engineers, whatever may be the branch of the profession in which they may be engaged, who can prove through their qualifications a right to be called Civil Engineers at all.

When the wide ramifications of modern engineering and the extraordinary number and variety of the problems with which engineers have to deal are considered, it will I think be apparent to every one that it is quite impossible for a single Institution to deal at all adequately with every branch of engineering. In 1818 and for many years afterwards it was almost inevitable that special importance should have been given to the great works of construction, such as roads, bridges, harbours, docks, lighthouses, etc., and that mechanical engineering which was of very recent growth should have been relegated to the position of the Cinderella of the Art. The Institution of Civil Engineers became associated in the public mind with a particular, even if a supremely important, branch of engineering; and in fact, while rarely forgetting its true function and its splendid ideal, it has throughout its career been not only maintaining the prestige of its representative character of general engineering, but has been a special exponent of the great constructional works of the character that I have named. I suppose, if that Institution could go back and make use of the experience gained in the course of its history, it would have organized itself on somewhat different lines, and would to a great extent have avoided the overlapping of work and multiplicity of societies which the present system, or want of system, has rendered inevitable. It is, however, open to question whether, after all, the science of engineering and the country generally has not benefited by the wholesome incentive of the separate and additional societies that have been formed. The *rôle* of the Institution of Civil Engineers can now only be fully met by the several branches of engineering science being separately organized under an acknowledged *entente cordiale* with the parent Institution. The oldest and most important branch of engineering next to the construction of the primary means of communication and of health is undoubtedly Mechanical Engineering.

In 1849, Joshua Field, the then President of the Institution of Civil Engineers, in the course of his Address said "Mr. George Stephenson was well known to us all. He was also President of a kindred Society, 'The Institution of Mechanical Engineers.' That Institution principally directs its attention to new inventions in the mechanical and manufacturing processes, whilst the communications brought before us are chiefly accounts of executed works in Civil and Mechanical Engineering. Thus, these two Societies embrace the whole science, and by combining their efforts, with mutual goodwill and a perfect understanding, they may and do confer great benefits on the public. Mr. Stephenson practised both as a Mechanical and a Civil Engineer, and attained equal eminence in both branches of the profession." *

Sir William Fairbairn, in a lecture given in 1859, "On the Rise and Progress of Civil and Mechanical Engineering," states: "When I first entered London forty-seven years ago (*i.e.* in 1812) there were no Mechanical Engineers." †

But what is really the special characteristic function of Mechanical Engineering? This will perhaps be made clear by considering the nature of works which cannot be considered as within its scope. Roads, bridges, railways, docks, harbours, dams, coast defences, are typical examples of so-called Civil Engineering, and you will not fail to notice that they are all of a foundational and stationary character; they are built for something else to run over or into, or simply as retaining structures. They belong essentially to the order of buildings and not to the order of machinery. Nearly all works of this character, though of primary importance, require to be supplemented by apparatus which it is the function of the mechanical engineer to supply.

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* Proceedings, Inst.C.E., vol viii, p. 29.

† Derby Mechanics' Institute.

The essence of Mechanical Engineering is "motion," while the essence of Civil Engineering is "rest." The life of a road is in its motors; a railway exists for its traffic which cannot be carried without the co-operation of the two great branches of the engineering profession. Docks and harbours are the direct results of the development of mechanical engineering in its application to ocean traffic, and the great dam at Assuan illustrates the importance of the mechanical engineer in providing the means of regulating the flowing water of the Nile.

Again, waterworks, sewage disposal works, gas works and electric-supply undertakings, which would perhaps not generally be considered as typical examples of mechanical engineering, are in fact very largely dependent on the mechanical engineer for their efficiency. Wherever machinery is required, there the mechanical engineer is wanted; but it is very far from my intention to suggest that every maker or driver of machinery is a mechanical engineer. I want to make it clear that mechanical engineering looked at from the professional side is of equal importance with any other branch for the successful carrying out of the great engineering works of the day, and is even more comprehensive. I quite recognize that there are many difficulties in laying down a hard and fast line of division, and that it may be practically impossible to say definitely whether, for instance, the permanent way of the railway is an example of mechanical engineering or not. In naval architecture, where exactly does the speciality of the naval architect end and the function of the mechanical engineer commence? In the carrying out of a great electrical undertaking, again it is impossible to draw a line and say—thus far, electrical engineering, and beyond it, mechanical. The practical outcome of all these considerations is that nearly every engineer, in order to be fully equipped for any special branch of engineering on which he may be engaged, should have some right to be considered a mechanical engineer.

Qualifications of Mechanical Engineers.—If you have followed me so far, you will begin to realize what I have in my mind. I have little doubt about the correctness of the views I have been expressing, and I may remind you of the great importance which the Institution of Civil Engineers now attaches to mechanical training in workshops. What then is the function of our Institution, and are we living up to the position which from the nature of the case we ought to occupy? The very comprehensiveness of the parent Institution of Civil Engineers renders, as I have already said, the existence of specialized institutions a necessity, and the hall mark of membership of these institutions, which are equally important in their respective spheres of influence, should be such that it can be recognized as the diploma of the special branch of engineering concerned. Can it be said that the qualification at present required from candidates for admission to our Institution would warrant such an assumption?

Now I am coming to close quarters on this question. I quite admit that the ideal of mechanical engineering which I am endeavouring to place before you, if carried to extremes might produce results which would be disastrous to the future of our Institution. The great difficulty is to distinguish between a mechanical engineer and a good artizan on the one hand and the commercial man on the other. Substantially I am maintaining that mechanical engineering is a profession; but like all professions not appertaining to what are known as the liberal Arts there is a great deal of buying and selling and artizan work mixed up with it. A very large number of men are employed in various capacities as managers, draughtsmen, engineers-in-charge, foremen and others who have really no grounds for being considered mechanical engineers, but who in considerable numbers seek admission to our Institution.

With regard to manufacturing, mechanical engineering has to do so largely with machinery, and the knowledge and experience required are necessarily accumulated to so great an extent in the works where the machinery is made, that manufacturing will and ought to enter largely into the practice of mechanical engineers. Workshop practice itself is recognized as an important part of mechanical engineering. Therefore, rules which may be especially applicable to Consulting Engineers are not of much service when applied to the majority of Mechanical Engineers. For example, the distinction that exists between consulting engineers and contractors in the construction of docks and railways is not usually present when machinery has to be put down. It is the manufacturer more often than not who supplies the designs as well as the plant. Of course, there are a large number of distinguished mechanical engineers who are not engaged in selling what they produce, but I think I may say, without fear of contradiction, that no one can design machinery properly who has not had large experience of its manufacture.

There are numerous problems on the scientific side of engineering that lie at the very foundation of successful design which need research. These problems can, possibly, only be fully dealt with when those engaged on them are without a direct interest in the practical uses of their solution. All such work has for its aim and object, however, practical use, and it is becoming more and more important that those who have to help engineers in their difficulties should themselves have more than a passing acquaintance with workshop practice.

For the great majority of mechanical engineers the commercial element will be present, and the Institution will fail in its duty to the profession and lower the status of its members if it does not control that element, and require evidence of knowledge and experience in the theory and practice of mechanical engineering quite apart from other considerations. I hope I shall not here be misunderstood. I believe commercial training and experience is desirable for all engineers. It is quite impossible for an engineer engaged in practical work to sever himself from the commercial factor. He is, in nearly everything he does, face to face with the problem to find out the least costly way of obtaining the required result, and has to answer the question "Will it pay?" But while the commercial factor is then of very great importance, the candidate for engineering honours should be an engineer first and a commercial man second, and it is particularly to be desired that our Institution should not confer corporate privileges on any other grounds than mechanical engineering knowledge and experience.

The By-laws of the Institution have laid down the minimum qualifications required to be fulfilled for admission to its several grades. The application of these By-laws rests with the Council, but it is impracticable for the Council to interpret them in a sense which does not accord with the general view of the members of the Institution. There is obviously considerable latitude in determining what constitutes a good general and scientific education, and what should be the nature of the responsibility attaching to the position occupied by the candidate to enable the Council to submit his name to ballot. You will no doubt all agree that a mechanic in charge of an engine and boiler is not for that reason to be considered a mechanical engineer. This case is put rather neatly by Disraeli (Lord Beaconsfield) in a decidedly scurrilous article written some 70 years ago on the ministers of the day. He said of one of these, "As a sort of extenuating compensation for the Cimmerian gloom of his unlettered mind they assure us he is a man of science. . . . We believe he has an air-pump in his house. A fine qualification this for the part he is playing. He would make a first-rate conductor of an omnibus."

There can be no doubt that the status of membership of our Institution depends upon the care which is exercised in admitting its members, and I desire to submit to your consideration whether the time has not arrived when all the younger men who desire to join as Associate Members should be obliged to furnish clear evidence of a general and scientific education up to some such standard as is required for admission to the Institution of Civil Engineers. In the event of adoption of a specialized examination of candidates not otherwise qualified, it would no doubt be found desirable that there should be certain distinctive features which would take the line of attaching great importance to workshop practice and the cost of work, so that the passing of such examination would give a guarantee of early training in the special subjects of mechanical engineering as distinct from the more general diploma of the parent Institution.

As I have intimated already, any action which the Council may desire to take in this direction must first receive the cordial support of the Members of the Institution, and I should like to add that I am throughout this Address expressing my personal view of the whole subject, and that what I say must not be taken as implying anything beyond that, or that I am speaking for my colleagues.

It will, I imagine, be evident to us all that there is a great deal too much uncertainty attaching to admission. There is a great want of some definite test of eligibility, particularly in regard to the grade of Associate Membership, which is so intimately related to training.

Full Membership is not nearly so difficult to deal with, as the class of members is confined to men of greater age and considerable experience and responsibility, and who presumably, whether with or without early training of a recognized character, have acquired in the course of their career a certain recognized position in the profession.

In reference to the grade of Associate Members, it is increasingly uncommon for young men at the age of twenty-five to have much responsibility in engineering; but at the same time if our Institution fully lived up to its ideal, every mechanical engineer would desire to become attached to the Institution at as early an age as possible as an Associate Member. Shakespeare, with prophetic instinct gives us some sound advice * : "Know you not, being *mechanical*, you ought not walk upon a labouring day, without the sign of your profession ?"

On the ground however of experience and responsibility alone, very few can be expected to qualify for admission much under the minimum age for full Membership. What then should be the main idea of the qualification for Associate Members ? Clearly there should be a thorough training in mechanical engineering, supplemented by a certain period of actual work done subsequent to training, but that work can hardly be expected to be of such a responsible character as would be essential in the case of a candidate who had not undergone the full training desirable.

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* *Julius Caesar*, I, i.

I have great sympathy with the young men in the profession who are doing what they can in subordinate positions, and who often with good training and application have lacked the opportunity for much responsibility. If it is known that the Institution requires a good education and a thorough engineering training as a preliminary to Associate Membership, the election of a candidate to that position at an early age and when occupying a subordinate post may be a great assistance to him towards improving that position.

Training of Mechanical Engineers.—During recent years there has been a greal deal of controversy as to the proper training of engineers; and it may not be amiss if I tell you my own view of the matter and something of my own personal experience. I became a pupil in the "Sixties" and entered the works of John Penn, as you know one of the very early Presidents of our Institution. I should like to say here how pleasant it is to think that my former chief occupied that position. Parenthetically, I may remind you also as a curious coincidence that only last month Mr. Aspinall on vacating this chair expressed the gratification he felt in the fact that his former master was also a Past-President. To resume, when I went to Penn's, I had just left school, and it was considered the correct thing to go straight into the workshop —in fact, there was really no choice at that time—specialized education in engineering except in the Navy was almost entirely absent; and while theoretical studies might be pursued at the Universities, practically all those who went in for mechanical engineering passed straight into the shops. There were a considerable number of pupils at Greenwich who altogether must have cost their parents a large sum. With regard to a great many, the whole affair was a pure waste of time and money. Every opportunity was given in the works to learn the business, and John Penn himself was always ready to assist when approached, but whatever one learnt had to be picked up. The more serious minded formed a little society, and, while there was plenty of the rough and tumble of early life, a great many evenings were given up to what might be called self-regulated studies of a general theoretical engineering character with the assistance of drawing boards and text books.

This sort of thing went on for two or three years, the latter part of the time, when engaged on erecting plant on board ship and attending trial trips, being, I think, the most productive period. After this I went into the drawing office and soon found that the brains of the whole business were there. It was run under the superintendence of a very able man, Mr. R. V. J. Knight, who was perhaps known to some of the older members, and it is an undoubted fact that I learnt more in six months in that office than in the whole of the rest of the time. Further, in a few months I had responsible work to do, and was very proud of myself when I had given to me the arrangement and ordering of the whole of the engine and boiler piping and fittings of H.M.S. "Volage." I mention this because it is typical of a bygone time and practice.

I have always felt that the first eighteen months of my time was more or less wasted, and that that period should have been passed at some college. I hold strongly the opinion that it is best for the majority of youths who are about to commence their engineering training to go to college on leaving school. It is a critical time of life and the comparative restraint of college life is then of great value, while the studies are pursued under conditions which are not far removed from those at school.

There is a great deal of difference of opinion on this question. Some consider that workshop training should come before college, and some think the concurrent or "sandwich" system is desirable. The latter does not commend itself to my judgment as satisfactory as regards the workshop part of it, though from the collegiate point of view I can well believe it may be. It must tend, I think, to prolong the period of training unduly, as the student on leaving college would, I should think in many cases, have to undergo a further period of probation in works engaged on the special branch of engineering to which he desired to attach himself.

The whole danger in the modern system of training engineers seems to me to lie in the effect it has of deferring the time of responsible work to too late in life. Young engineers nowadays start their life's work two or three years later than they did fifty years ago, even if very much better equipped for that work.

It must never be forgotten that it is "the man behind the gun that counts," and if young men are tied too long to the "apron strings" of tuition, individual energy, dash and courage may wane. Therefore I feel that the examination period should be got over as soon as possible, consistently with sound work, and the practical training which follows should be more specialized in the branch of engineering selected. I quite agree that where the college courses permit, part of the long vacations could be most usefully spent in works, but it is somewhat difficult to arrange for such temporary admissions.

I am strongly opposed to early specialized training in the sense that boys should be taught a smattering of engineering. There are boys who have a natural aptitude for certain studies. Broadly speaking, however, there are only two kinds of minds and temperaments—the mathematical or scientific and utilitarian, and the classical or literary and artistic. I suppose everyone's mind is more or less a flux of those two elements in different proportions, and individuality is due to the preponderance of one over the other. However that may be, it is the boys' minds that require training at school, and what they learn of the subjects of tudy is of minor importance.

I was discussing this subject some years ago with a late head-master of Clifton College, and he told me that in his own experience he had found that boys on the classical side, when they went over to the modern side during the latter part of their schooling, in order to specialize in certain subjects, would beat the boys on the modern side in those subjects, though the latter had been working at them for years. An explanation offered was curious and bears upon this question of early training, namely, that the boys on the classical side were better taught and had learnt better the art of learning.

I believe at the present time there is no difference of opinion on one point, namely, that engineers are not made at college or at the technical schools. The function of these immensely useful Institutions is to furnish the students with the intellectual tools required in the course of their work, but the students must subsequently learn how to use these tools in the workshop and in the office.

There are large numbers of young men who cannot get the advantage of a collegiate training and who enter works as ordinary apprentices. I am very far from desiring that such should feel that because of this they cannot look forward to joining the Institution. There are generally facilities to be obtained in Technical Schools for evening classes, and most employers are anxious to help on deserving lads, who if they show promise will have drawing-office experience arranged for them. There is no reason why they should not be able by sustained effort to fulfil the requirements, and, if they do, they are not unlikely, as picked men, to go far and render great service to the Institution. It can be no one's wish that rules should keep such men out, but, as I said earlier in this Address, the Institution is intended for Mechanical Engineers. The test for admission should be high, both from the point of view of general and technical education and of practical work. It should always be kept in mind that the members of this Institution ought to have had not only a good theoretical and practical knowledge of mechanical engineering, but should be prepared for the control of engineering industries and the workmen employed in them. Therefore, they should have gone through the training and have had the preliminary experience which might be expected to fit them for such control.

Graduates.—If there are difficulties in regard to the qualification of candidates for the honour of admission as Members or Associate Members, I am not sure that there are not serious difficulties with regard to the Graduate class. It is a source of gratification to know that this is a flourishing branch of the Institution, but it is capable of great extension both in point of numbers and in usefulness. From the particulars which one finds in the applications for admission which come before the Council, it would appear that there are many hazy ideas afloat as to what is the kind of training which Graduates are expected to be obtaining.

The whole object of the Graduates' class is to make a way through which young men may enter without further difficulty the inner courts of the Institution, and the stricter the rules are which govern admission to the class of Associate Membership, the more important it becomes to lay down as clearly and in as detailed a manner as possible the minimum qualifications as to education and training which have to be acquired during the Graduate's life from eighteen to twenty-five years of age.

In the case of our Institution especially, I am of opinion that a well-considered and specialized examination in mechanical engineering for Graduates between the age of twenty-one and twenty-five would be of great service to many and be of great advantage to the Institution. The passing of such an examination, or its equivalent outside the Institution, together with a sufficient works' and office training, would then give an immediate entry into the Associate Member class, provided the candidate was engaged in engineering work.

Older candidates seeking admission, who might not possess the minimum credentials, would have to wait until their experience and position warranted a waiver. I am quite aware that an examination test taken alone is a very poor guide to real knowledge or ability, but this Institution is not at all likely to give too little weight to practical work. An examination of the kind indicated would at any rate entail a considerable amount of study of the theoretical side of engineering, including workshop practice.

I do not come before you to-night with a cut-and-dried scheme. I have been throwing out hints or scattering seed in the hope that it may bear fruit in the future, and may be the means of creating a body of opinion amongst the members on which the Council may take action.

Associates.—There is a class of Associates of this Institution, which has been specially designed with the object of securing the support and assistance of men who, while not mechanical engineers or even engineers at all, have interests common to Engineering and who are experts in special departments of knowledge from which engineers can take toll. For some reason this class of Associates has not much increased in numbers of late. There has apparently been an idea abroad that an Associate of this Institution was someone who was an engineer of a sort, but not a good enough man to be a Corporate Member; whereas the real idea of the By-law relating to Associates is that no engineer can be an Associate, and that the position is one which is intended to convey that the person who occupies it, is recognized as something of a master in some other cognate branch of science or of the practical arts.

The question has been raised whether this idea of the status of Associate is the most useful, and whether the interests of this Institution would not be better served by sacrificing to some extent the idea of eminence conveyed, and regarding principally the occupation of the candidate. My own view is—that the better the status of Membership, the more important it becomes to guard the entry to the Institution by the Associate door. Here again it is the opinion of the members generally that must determine the policy to be pursued.

Research and Other Matters.—A very important part of the Institution's work in recent years has been that of "Research." Our Proceedings bear witness to the valuable work that has been accomplished. Research Committees have conducted investigations in Riveted Joints, Alloys, Friction, Gas-Engines, Marine-Engine Trials, the Value of the Steam-Jacket, and the Steam-Engine. At the present moment there is not quite the same activity, with the exception of the Alloys Research, but it is to be hoped that the next ten years will be equally productive. There are many unsolved problems relating to mechanical engineering on which research is needed. One very important subject is the Fatigue of Metals. Another is the question of Vibration of Machinery and the methods by which it can be avoided or its influence restrained. There are questions relating to the problems of the Navigation of the Air. There appears to be very little data available in regard to Water-Hammer, and another question in which I am particularly interested is the effect of Compound Stresses on Cast-iron Pipes.

It was not, however, to suggest subjects of research that I have referred to this branch of the work of the Institution, but to call attention to the fact that there is a considerable amount of independent research going on under the auspices of different Institutions without any attempt at co-ordination. The work would be more effectively and economically done if these different bodies would organize themselves something after the manner of the Engineering Standards Committee which, with the support of the five leading Engineering Societies, has done such remarkable and excellent work, and which will undoubtedly remain a permanent organization of the Engineering Profession.

There is nothing so efficacious as research to make one realize what a number of different departments of knowledge and opinion are brought into play in order to solve these engineering problems, and what an amount of co-ordination between science and practice is needed to secure real success. Our Institution through its organization and membership should exhibit a like catholicity.

Another matter of importance to members of this Institution, which has been under the consideration of the Council for some time past, is the question of the publication of Mechanical Engineering Abstracts. There is a strong body of opinion amongst the members in favour of the proposal. To be of value this work must be thoroughly well executed and in a convenient form for reference. As in the case of research, the need of co-ordination is felt, and it is to be hoped that means may be found to focus the whole of the engineering work of this character for distribution to the various institutions which are interested in the special branches of the subject.

It has been felt by the Council that there is a good deal yet to be done to make the Library of the Institution fully available to the members, and a card-catalogue is now being made with the advice and assistance of a librarian, Mr. R. A. Peddie, who has a unique reputation in this sort of work. In these busy days there are few who can give the time to independent research in a library, however well-arranged and indexed, and it is not perhaps as widely known amongst the members that the library staff is ready to render assistance in searching the Library on behalf of members seeking information on special subjects. This kind of work is excellently done and is most useful, as I can testify from personal experience.

Apart from all these questions which I have been discussing, the social element has a very important bearing on the work of such an Institution as ours. What really is at the bottom of all this extraordinary development, in recent years, of institutions and societies of men and women engaged in all kinds of occupations? It is essentially our gregarious nature which is in evidence. This is shown not only in the general desire for association with one's fellows, but in the particular desire for comradeship with those engaged in similar occupations. Sentiment, I take it, was the prime mover, and the economic value of the social element was a later discovery of science. The touch of fundamental human nature which "makes the whole world kin" is a splendid heritage from the past, and the social instincts correct the evils that arise from the fierce competition which exists in many departments of industrial activity, and help to soften the seemingly pitiless doctrine of the "survival of the fittest." There is clearly no progress apart from that fact, but what these institutions teach us socially is to "play the game." I have alluded already to "rules of conduct," and drawn attention to the great difficulty of formulating detailed rules of universal application, but while "rules of conduct" may vary, there is no doubt in any one's mind that men who do not "play the game" are rightly punished by social ostracism.

It is one of the functions of Engineering Institutions to promote the friendship and goodwill of rivals in the severe competition of their lives. There is nothing I think which we, in Great Britain and in the Empire at large, are prouder of than the sporting instinct of which we are the acknowledged exponents. That instinct should have free play in our business as well as in our pastimes, and I am proud to believe that our Institution exemplifies this doctrine in a very emphatic way.

It is however about time that I should bring this rambling discourse to a close, and it is only a natural sequence that I should wind up by reminding you that the practical work of the Institution cannot be adequately carried on without large funds and a well-furnished home. The Institution has grown in a very remarkable degree since it first entered this building twelve years ago. There were then about 2,700 members, showing an increase of about 1,000 in the previous twelve years. The present number is 5,700, so that the membership has more than doubled, and the annual income has increased from £8,300 to £15,600. My own service on the Council commenced shortly after the occupation of the new building, and I can speak from personal knowledge that the inconvenience and restriction, particularly of the office accommodation, was felt from the first. If so, you can quite understand that, with the present work of the Institution, the conditions have become really intolerable.

An opportunity of acquiring a site at the corner of Princes Street and Old Queen Street occurred two or three years ago, and a building was about to be commenced which would have given useful additional offices, when it seemed desirable to defer the whole matter pending the settlement of the plans of the new building of the Institution of Civil Engineers. On several occasions during the past ten years it had been suggested that we should purchase the Storey's Gate Tavern, and eventually, as you are aware, this property has been acquired, so that the Institution is in possession of the whole frontage to Princes Street from Storey's Gate to Old Queen Street. The setting back of the new building of the Civil Engineers has removed the former insuperable difficulty of building to a sufficient height, but has introduced another and most difficult problem, namely, how to harmonize the elevation of the new building in Princes Street with that of the Civil Engineers, and in such a way that the new part will also architecturally accord with the old.

It seemed to the Council pre-eminently a case for competitive designs, and I am very glad that it has been possible to exhibit on the walls to-night the four designs which have been submitted. It is probable that certain modifications will have to be made in the plans, and until the old building No. 1 Great George Street is removed, it may be that the whole building cannot be completed, but sufficient can be executed without delay to give the Institution the additional accommodation that is wanted. There will be an enlarged entrance hall and staircase. The secretarial offices will be on the ground floor—a committee room and other offices on the mezzanine—and a council chamber, forming in fact a continuation of the library, on the first floor. At the present time it is necessary to close the library to members when the Council is sitting. Part of the floors above will be available for letting. A good second staircase is provided which will serve these floors and be available for the use of the Institution, and give circulation on gala nights.

There can be no question as to the great improvement that will be effected by these works in promoting the convenience and comfort of the members. The Institution will on completion possess a home of which, by reason of the nobility of its design and the beauty of its detail, the members may be proud, and they will further be able to feel that they have only done their duty in placing the finishing touch to what may be expected to be one of the most notable corners in the Metropolis.

I refrain from telling you what it is going to cost, as at the moment any estimate is unreliable, but there is no reason for supposing that there will be any more financial difficulty in executing this work than there was twelve years ago in connection with the existing building. The annual charges will necessarily be larger, and with increasing demands on the funds of the Institution for such objects as I have mentioned in the course of my Address, a larger income will be required.

It must not be overlooked that while the Institution, even in numbers, is likely to benefit largely by an improvement in the status of membership, it is quite possible that a strict interpretation of the By-laws may at first lead to some check in the rate of increase of membership, so that if you want all these things and desire to see the Institution take its proper place as the acknowledged representative of Mechanical Engineering in this country, you must, if required, be prepared to give it adequate support and make some sacrifices to endow it with the necessary funds.

This is not the occasion on which to enlarge in any detail on financial matters. We have in the past been taught that money is the root of all evil. It is equally true to say it is the root of all good, and I doubt if it is possible to point to any expenditure of money on any object which is more essentially and absolutely good as in supporting such an Institution as ours. The only end to be served is that of promoting the honour and prosperity of the profession to which we belong, which is inextricably bound up with the prosperity and good, not only of our own national industries, but also with the development of civilization in the world at large. It may be said that such a statement is altogether too idealistic, and that if good work is to be done there must be a sufficient personal reward to the workers. I would answer that good work is rarely wanting in reward, but I would like to appeal to the experience of most engineers whether in fact their best work has not been done mainly for the pleasure of doing it, and that where the desire of immediate gain is prominent their work deteriorates. I think the history of the work of many successful painters illustrates this point. The painter's early work, when he is trying to please himself and obtain recognition, has a certain value which is lost when the money comes pouring in, and is only regained in later life when the money ceases to attract.

This sort of experience is also shown on a larger scale in the history of our own country during the development of mechanical engineering in the last century. The work of our predecessors of 100 and more years ago brought the world to our feet, the country became wealthy beyond the dreams of avarice; the quality of the work produced deteriorated and other nations forged ahead. The present generation, when power seemed to be failing, is recovering the position, and its success is based on the soundness and superiority of its work. That is the only basis I believe on which the future prosperity of Great Britain can depend. Our ambition throughout should be that everything we make should be the best of its kind, and, if we succeed, the world will be again at our feet within the necessary limit of our means of production. That surely is a "consummation devoutly to be wished," and if we, as an Institution, act wisely we shall exercise an important and salutary influence on the future development of the industries of our country.

Sir WILLIAM H. WHITE, K.C.B., Past-President, said it was his pleasant duty, as the senior Past-President present, to propose that the best thanks of the members should be given to the President for his most interesting Address, and that he be requested to permit it to be published in the Proceedings. The President had given so many years of service and so much work to the Institution that any suggestions he might make as to what would promote its increased usefulness and future prosperity, or any remarks he might make on the training of engineers, necessarily deserved the closest attention. Members of the Council knew more fully than members generally could do what the President had done for the Institution since he joined the Council about twelve years ago. In Mr. Ellington's presence he did not desire to say much about that subject, but he felt bound to say—and he was sure that the immediate Past-President and other recent Past-Presidents who

(Sir William H. White, K.C.B.)

were not there that night, who came immediately before Mr. Aspinall, would bear him out in the statement—that as Chairman of Committees, Mr. Ellington had done a great work. There had now been three Presidents in succession who had been non-resident in London, and during that period the Institution owed more to Mr. Ellington than was conceived of by most of the members. The fact that the Institution drew so largely from members non-resident in London in its selection for the Council and for the Presidency, was in his judgment a source of great strength, and he hoped that practice would always be continued. But it remained true that in the daily work of the Institution there must be associated with the Secretariat—even when Mr. Worthington and his staff were working at high pressure—an element of guidance, advice and control from amongst those Members of Council who were resident in London. In dealing with urgent and important business and certain special matters that had arisen during the last six years, Mr. Ellington had done wonders, and he desired publicly on behalf of the Council to make suitable acknowledgment. To-night the President came forward and made suggestions, some of which were of a very radical character; respecting some of these suggestions there was serious ground for difference of opinion, as the President himself would acknowledge, but members of the Institution would do well to give careful heed to all of these opinions, because of the special experience of the author.

It so happened that he (Sir William White) was President of the Institution when the new building was first occupied. At that time he ventured to say that when the Institution thus took its place in the face of the world by erecting the new building in a commanding position and providing increased accommodation for members, great developments could be hoped for in the future. Mr. Ellington had shown them that night that those developments had been realized. The numbers of the membership had been more than doubled, and the income had nearly doubled. The Graduate class, which the Institution was able for the first time to help adequately in the new building, had grown into a most flourishing and increasingly useful branch of the membership of the Institution. The remarks which the President had made were of course not open to discussion. That was one of the privileges of a Presidential Address. In fact, in that respect a President assumed a position equal to that of a clergyman, a position which was unrivalled for the possibility of saying what could not be challenged, at least openly. He ventured to suggest that the President should pick out the most debatable points of the Address and put them forward in the form of a Paper which could be discussed. If the President would take that action, he would promise to come and take part in the discussion, and as he differed from the President on certain details there would probably be a good time. Members had given a vigorous cheer when the President said he thought the time had arrived for the imposition of an examination test on all newcomers. It was a remarkable thing how men who were inside an Institution were disposed to favour the adoption of stringent measures in regard to the admission of others. He noticed that in recent times the idea of compulsory service in the National Defence found its warmest advocates amongst men many of whom were too old to serve. Speaking seriously, he desired to say that while there might be differences as to details, there was undoubted agreement in the principle, that if the Institution was to be made what all the members sincerely desired it should be, the Council and all the members must join in the effort to raise the standard of attainment and qualification necessary for admission to membership. There was no doubt about that. Speaking as a man who had been examined in his earlier days as much as any living man, he would add that mere multiplication of examinations was undesirable, and that a violent or sudden change of system was also undesirable. In making those two statements he thought he felt confident he should have the hearty support of the President.

The President had spoken very fully with regard to the new building, but there was one further reference he would like to make. Mr. Ellington was Chairman of the Building Committee, the Committee which he quietly said had made recommendations

(Sir William H. White, K.C.B.)

to the Council which the Council had that day approved. In that capacity Mr. Ellington had served the Council marvellously well. It was not an easy task to frame conditions for a competition such as had now taken place. That competition had brought about the choice of a design by the Council, a design which would make the home of the Institution one of which all might be proud. All that work had been carried through under the Chairmanship of Mr. Ellington, and all members would be delighted if it was found possible to have the work of extension completed and the building reopened during the Presidency of Mr. Ellington. Although criticism was barred, as he was a purist in matters of the Scriptures he was bound to point out that the President had not done justice to an ancient volume when he said that it taught that "money was the root of all evil." That was not the teaching: it was the *love* of money. Having corrected the text, might he add that the new building would be undoubtedly worth the money it would cost, and would prove an investment which would come home and help the future of the Institution in a way that could hardly be overestimated. He sincerely hoped that the wise words the President had spoken that night, as to the effort to raise the necessary funds being one in which all who loved the Institution or belonged to it should join heartily and give their best help, would be taken to the hearts of all who had heard them that evening, and would appeal to thousands who would read that Address and who wished well to the Institution of Mechanical Engineers.

Mr. HENRY DAVEY, Vice-President, said it was his pleasant duty and privilege to rise to second the vote of thanks that had been so ably proposed by his friend, Sir William White. As he was sitting there and wondering what to say a brilliant idea occurred to him, but, unfortunately, Sir William White had anticipated him in giving it utterance. With Sir William's great perception and facility of expression he had discovered and put into words what he himself was going to say in a less brilliant manner. It had occurred to him that the Mechanical Engineers had three very good things: they had the Institution, the Building in which they were housed, and a good and capable President. The President had been associated with the development of the Institution and its prosperity, and had done very great work towards the attainment of the splendid position which the Institution had reached. He had had a good deal to do with the present building and very largely to do with the organization of the idea of the extension of the building, so that the Institution would have a better house than they had at present. It was quite impossible for those who had not had the opportunity of sitting with Mr. Ellington on the Committees and at the Council table to realize the amount of work he had undertaken for the good of the members. Without saying more, he had the greatest pleasure in seconding the motion that had been so ably proposed.

Sir WILLIAM WHITE said he would like just to repeat the terms of the Resolution: "That the best thanks of the members of the Institution be given to the President for his Address, and that he be requested to consent to its publication in the Proceedings."

The Resolution was carried with acclamation.

The PRESIDENT said he had listened with surprise and also with pleasure to what had been said as to the work he had done for the Institution during the past ten years. Of course it was very gratifying to have such an opinion expressed of one's work, and he felt it very deeply, but he only wished he really deserved it. He had of course given much time to the work, but that had been largely accidental, the fact being that he had been very readily available to the calls of the worthy Secretary of the Institution, Mr. Worthington. He had really only served the Institution as anyone else would have done in his position. Members of Council occupying a position where they could work, usually felt it to be a matter of pleasure and duty to do it, and it was really in consequence of his having been comparatively easily available that the members had heard the expressions used towards him that evening. At the same time it gave him great encouragement, and

(The President.)

he sincerely hoped that when the time came for him to vacate the Chair he might have as cordial a greeting for what he had done during its occupation as he had had when only just beginning his career as President.

The Institution of Mechanical Engineers.

TWO LECTURES ON STEEL.

By Dr. WALTER ROSENHAIN, of the National Physical Laboratory, Teddington.

First Lecture.

Tuesday, 11th April 1911, at 8 p.m.

Edward B. Ellington, Esq., *President*, in the Chair.

The President said that, before he called upon Dr. Rosenhain, he would like to say that these Lectures constituted somewhat of a departure from the ordinary practice at this Institution; and it had arisen in the following way. Since 1897 the Institution had been engaged in a number of researches on Steel; first of all under the direction of the late Sir William Roberts-Austen, and subsequently under the National Physical Laboratory. In the result it had been felt by many that the subject was of so complicated and technical a nature that it was very difficult for members not conversant with the research to follow all the Reports. Then there was a Paper read last December upon the Constitution of Troostite, and Dr. Hele-Shaw suggested that it would be interesting and acceptable to the members if Lectures on the structure and physical properties of these Carbon and Iron products could be arranged, which would present the subject in a little more homely fashion, as a kind of introduction to the study of the Reports. That suggestion had been considered by the Council, who were fortunate in being able to induce Dr. Rosenhain, one of the great authorities on this subject, to prepare these Lectures. He would now call upon Dr. Rosenhain to deliver his first Lecture.

Dr. **WALTER ROSENHAIN**: Mr. President and Gentlemen,—The task which your Council has set me, when it did me the honour to ask me to deliver these Lectures, is a formidable one—formidable for two distinct classes of reasons. In the first place, on account of the mass of information which has been accumulated by the successive researches of a great number of investigators in the 46 years which have passed since this subject was taken up in anything like the present form. This material is so enormous, that it is a tax upon both the powers of the lecturer and of his audience to present any coherent account of it in the course of two lectures. Then, secondly, there is the difficulty that the subject bristles with questions upon which entire unanimity has not yet been reached; and in presenting a subject of that kind, one is always faced with the difficulty of either fogging one's hearers by too judicial an attitude, or being accused of partiality in presenting what some would call a one-sided view. The only way, however, of presenting this subject is to take the point of view of one particular theory, warning you that there are other theories. But I hope, throughout what I have to say, to preserve as fair an attitude as possible with regard to other people's views, and I will try to show clearly what is fact and what is inference or theory.

If one looks back to the history of Metallography, that is to say, of the science of the structure and constitution of metals, one might trace it back to the year 1600, when Gilbert discovered that an ordinary steel magnet ceases to be magnetic when it is made red hot. That is the first observation on the changes undergone by iron and steel when raised to a high temperature. From that time the subject may be said to have developed in two distinct directions—directions representing the two methods of investigation which are still the principal means of attack on this subject. One is the study of thermal phenomena, that is to say, the phenomena connected with heating and cooling in iron and carbon alloys. The other is the study of the structure of the alloys when cold.

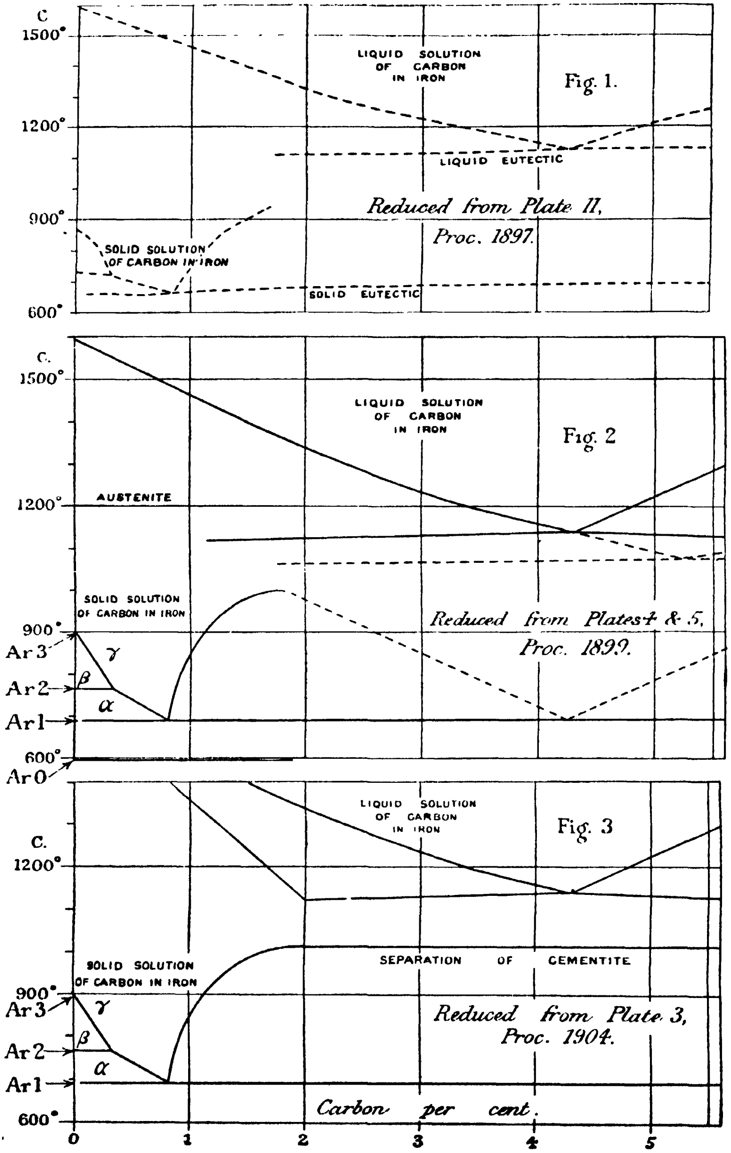
The thermal line of work was begun only comparatively recently. If we omit Gilbert's observation, to which I have just referred, I know of nothing very important that was done until the year 1873, when Professor W. F. Barrett — who is still, I am happy to say, amongst us—discovered and studied the phenomenon known as Recalescence. He showed that if a piece of steel, and particularly steel which contains about 1 per cent. of carbon, is heated to a red heat, and then allowed to cool down in a darkened room, it grows progressively duller and duller, until it reaches a point when it suddenly resumes its incandescence, and becomes vivid again; at that point there is a sudden evolution of heat, and the mass, as it is called, "recalesces." After that, there was the work of Guthrie, who threw a great deal of light on the behaviour of alloys in general by his work on what he called "eutexia," that is to say, alloys which are the most fusible substances which can be formed by combinations of any two or any three metals. His work largely helped subsequent investigators to understand the whole question of the theory of binary alloys. After Guthrie came Tchernoff, in St. Petersburg, who first noticed the connection between the critical point, that is, the "recalescence" of Barrett, and the hardening of steel. Then came the work of a man who has done a great deal, in a more or less indirect manner, to further the study of steel, and that is H. Le Chatelier. His introduction of platinum thermo-couples for the measurement of high temperatures laid the foundation for the accurate thermal study of alloys generally, and of steel in particular. It was left to Osmond, in 1890, to bring out, in his classical Paper, which was read before the Iron and Steel Institute in London, a full account of the cooling curves of iron and carbon alloys. That Paper is well worthy of attention, and it contains many facts which seem to have been neglected; in fact, some of them seem to have been rediscovered quite recently. Thus "the fourth recalescence in steel" was the subject of a Paper, and was announced as a discovery early last year, yet a clear account of the double nature of "Ar2" is to be found in Osmond's Paper of 1890.

The other line of development—the examination of the structure of iron and steel—may be dated back to Robert Hooke in 1665. Hooke found that crystals were observable in an alloy of lead and silver as it cooled, and he also made some observations on the appearance of polished steel, observations which are interesting reading in the light of our knowledge to-day. After Robert Hooke we have a contribution from Réaumur, who touched upon so many kinds of work; for instance, there is Réaumur's porcelain, and Réaumur's malleable iron. He introduced the idea of optical aids in examining fractures of metals; and he suggested that iron possessed a polyhedral crystalline structure. After Réaumur, we have the next step made by Widmanstaetten in 1808. He was the first person to polish a metal with a view to observing its structure. The things which he observed did not require the use of a magnifying glass. His observations were on surfaces of meteorites which were polished and, I think, etched, but without magnification. It was left to Henry Clifton Sorby, in Sheffield, in 1864, to prepare metallic sections such as we know them now. He developed the technique of grinding and polishing these sections, and illuminating and examining them with considerable magnifications, such as the modern microscope renders available. Sorby may be considered to have laid the foundation of the microscopical examination of metals. But that work remained nothing but a foundation for many years. It was neglected until Martens, in Germany, and Osmond, in France, quite independently of Sorby's work—I think they knew nothing whatever about it—took up the microscopical examination of metals. Sorby's work was then unearthed, and exerted a very powerful influence, particularly on the nomenclature of the subject. Now Sorby was really the founder of microscopical petrography—that is to say, the study of the structure of rocks by means of the microscope. He looked upon steel as a kind of igneous rock, only steel being an opaque body, which could not be cut thin enough to enable one to look through it, he had to develop a different technique for the examination of opaque sections, but he still regarded it from the mineralogical standpoint, and in consequence he originated a nomenclature which is to a large extent to be blamed for the origin of these Lectures. It is responsible for that whole row of "ites"—"austenite," "cementite," "pearlite," "ferrite," and the rest; these are simply names based on the analogy of names given to various species by the mineralogist; some of them are derived from personal names. I cannot help thinking that it is a pity that personal names were ever adopted; they have not been adopted in metallography in connection with any other metal except iron. In the metallography of copper alloys we speak of Alpha, Beta, Gamma and Delta constituents, and we live in peace. In regard to the personal names given to the alloys of iron and carbon, there has not always been peace.

The history of metallography next brings us to a name which has already been used by the President, one which cannot fail to be present to the mind of any metallurgist speaking in this room—Sir William Roberts-Austen. As you are aware, he carried out the work of the Alloys Research Committee of this Institution for many years, in fact until his death. This work is so closely associated with this subject that, in order to recall it to your minds, I have asked the Secretary to have placed on the wall three diagrams which largely represent the results of Roberts-Austen's three researches with iron-carbon alloys. Their dates are 1897, 1899, and 1904. Outlines of these diagrams are reproduced in Figs. 1, 2, and 3 (page 246). The last one was finished after Roberts-Austen's death, by Professor Gowland and Mr. Merrett. Roberts-Austen obtained the data upon which the first equilibrium diagram of the iron-carbon system was based by Rozeboom, who worked out the theory of the subject very fully. Now it is upon the understanding of this equilibrium diagram that the whole knowledge of the subject turns, and it is this equilibrium diagram which I wish to describe first of all.

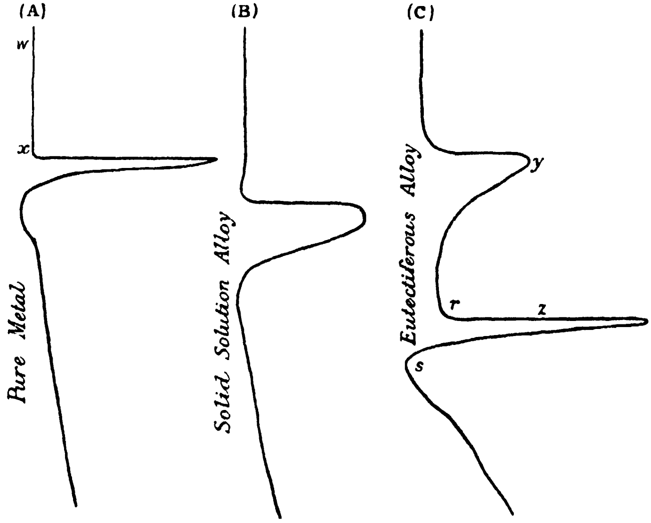
First as to the facts which are contained in it, because an equilibrium diagram is a statement not only of facts, but an indication of the interpretation of those facts. And I want to try and show clearly where the facts end, and where the interpretation of the facts begins. The facts which are contained in any

FIGS. 1, 2, and 3.—*Freezing-point Curves of Carburized Iron, reproduced from 4th, 5th and 6th Alloys Research Reports.*



equilibrium diagram are temperatures—nothing but temperatures. Those temperatures are obtained by watching, with a suitable instrument, the heating, or probably more conveniently the cooling, of a piece of metal of known composition. And when you do that, and properly record what you have seen—your instrument may record it automatically—you obtain a heating or cooling curve representing the cooling of that metal. Fig. 4 shows some examples of such cooling curves plotted in the form known as "inverse rate" or "derived differential" curves. The observations for the "inverse rate" curves are taken by determining the time which the metal occupies for every fall of temperature of (say) 3° C., and these times are plotted as abscissæ, against the temperature, which is plotted vertically as ordinate. In such a curve, steady cooling appears as a smooth more or less vertical line, while any retardation of cooling is represented by a sweep of the curve to the right. Taking as the simplest case a pure metal like copper, and

Fig. 4.—*Examples of Cooling Curves in form of "Inverse Rate" or "Derived Differential."*



commencing at 1,200° C. (2,192° F.), when the metal is quite liquid it will cool steadily, and every fall of 3° will occupy the same length of time; the curve is thus almost a straight line, like *w x*, Fig. 4A. We now come to the point where the metal begins to freeze. It immediately ceases to cool at anything like the former rate, because during the freezing process the metal gives out heat, and that latent heat which is being liberated balances the loss of heat which would otherwise cause it to cool. Therefore, for a time, the temperature of the mass of metal remains stationary. And during this interval, which may occupy several minutes, the curve makes a sweep to the right. When the metal has solidified, the rate of cooling increases again, and the curve returns. For a time the cooling is faster than before; the metal has lagged behind its surroundings and cools faster for a time so as to catch up, as it were; afterwards cooling continues steadily down to the ordinary temperature.

That is the typical mode of cooling of a pure metal; it has a definite freezing point and nothing else—its cooling curve is of the simplest kind. Now take an alloy of a particular type, which we shall learn to know presently as a solid solution—that is to say, an alloy which freezes without any separation of the two constituents present. The condition of solution which exists above the melting-point remains after the metal has solidified, and its structure is very much like that of pure metal, but its freezing curve is different. Such an alloy does not give a single sharp point, but a wide peak, covering a considerable range of temperature, which may be anything from 10° C. to 150° C. Fig. 4B is the typical cooling curve of a solid solution alloy, in which there is no further change on cooling down. There is another type of alloy, which is shown diagrammatically in Fig. 4C—and diagrammatic representation is sufficient for our purpose here. This is an alloy which forms one of those eutectics which Guthrie discovered. Here there is steady cooling to the point of commencement of freezing; and there is then at *y* a peak, not quite so sharp as that found in the case of pure metal, but sharper than that of a solid solution. After the first peak, retarded cooling goes on for a considerable time; this is not due to the alloy freezing as a whole, but only the predominant constituent is freezing, and the remaining liquid is steadily changing in composition. When an alloy of this type, containing (say) 80 per cent. of A and 20 per cent. of B, begins to freeze, it deposits crystals of A, while the liquid becomes richer in B than it was originally. While this happens the temperature is falling, and a peculiarity of these alloys is that when the composition of the liquid has reached a certain stage, which is the composition of the eutectic (or most fusible) alloy of the series, the freezing temperature of this most fusible alloy is also reached, and the remainder of the liquid solidifies as a single mass at this temperature. In Fig. 4c (page 247) we see the "peak" of initial freezing at *y*, retarded cooling from *y* to *r*, the "peak" of the eutectic solidification at *z* and smooth cooling below *s*. Sometimes alloys are more complex; Fig. 5 shows an actual example, with the plotted curve. This is an alloy containing 90 per cent. of zinc, and 10 per cent. aluminium. Here the alloy begins to freeze at A, then it is like the curve I described just now with a eutectic peak at B, but below this there is another peak. This solid alloy evolves heat on cooling to that temperature, and when it evolves heat, it

Fig. 5.
Cooling Curve of Zn Al Alloy.

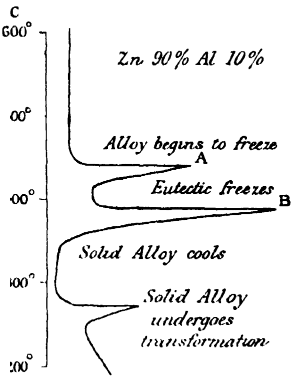
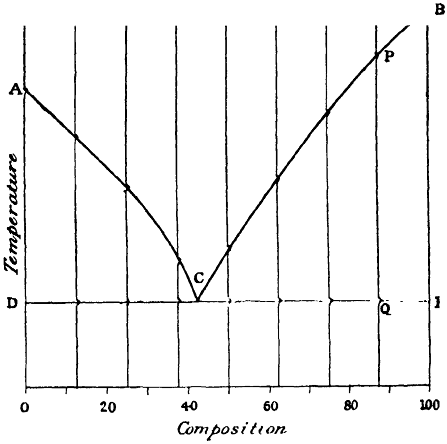


Fig. 6.—*Cooling Curve for a Series of Alloys.*



undergoes transformation. Such heat evolutions and transformations are frequently met with in alloys, and nowhere more than in the alloys of iron and carbon.

If such cooling curves as these have been obtained, not from one individual alloy, but from a series covering the whole range of possible composition of the alloys of two metals, it is possible to group these curves together into a single diagram. Fig. 6 (page 249) illustrates diagrammatically how this is done: each of the vertical lines with its peaks represents the cooling curve of an alloy whose composition is indicated by the position of the line along the horizontal axis of compositions. A cooling alloy containing 90 per cent. B, for instance, has its first freezing at P and its final eutectic solidification at Q. If these cooling curves are placed each in their proper position or concentration, and if we plot on the temperature scale the various arrests found on the cooling curves, we find that these arrests can be joined together by curves like A C, C B, and it is easy to see what those curves mean. Above the curve A C B the alloys are completely liquid, because it is only when any point on that line is reached that freezing commences. Below the line D C E the alloys are completely solid, because as soon as an alloy reaches that temperature the eutectic freezes, and the whole mass is solid. Between these two curves we have a region of mixed solid and liquid. Now I want to give you the names which are technically applied to these curves. The line A C B, limiting the liquid region, is spoken of as the "liquidus," and the line D C E, below which the alloys are completely solid, is called the "solidus."

I shall now pass on to the equilibrium diagram. Fig. 6 (page 249) represents the rudiments of an equilibrium diagram, but it is not a complete diagram, because it only records the facts—the temperatures of freezing, commencing freezing and final freezing, and the temperatures of heat evolutions in general. But if we interpret it and say what is the meaning of the various lines and regions we are converting it into an equilibrium diagram, which states not only the facts, but also the inferences which we draw from those facts.

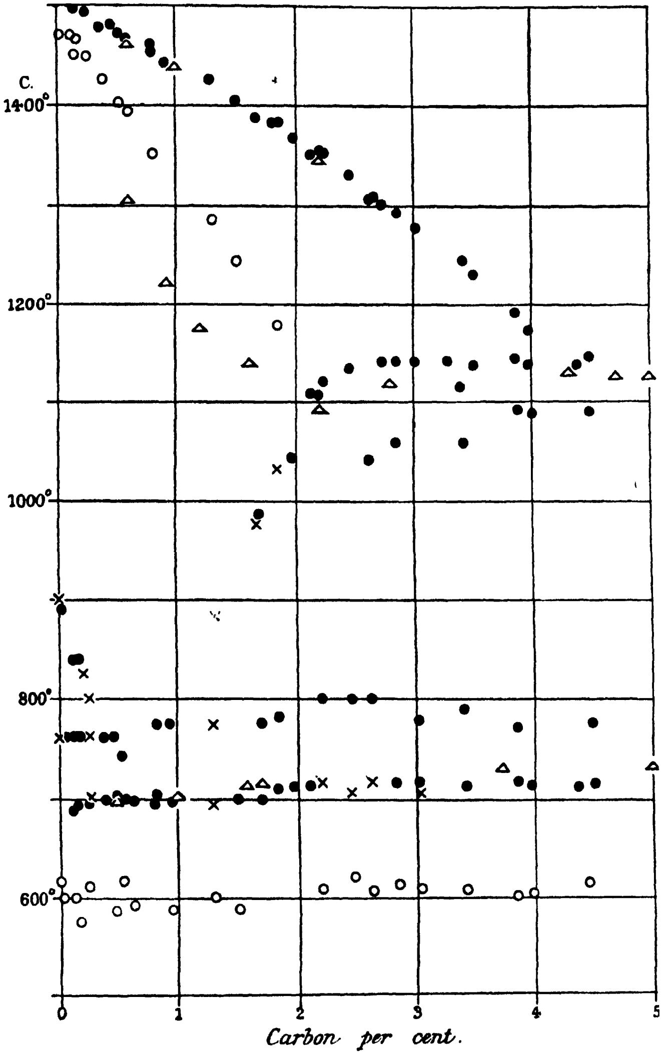
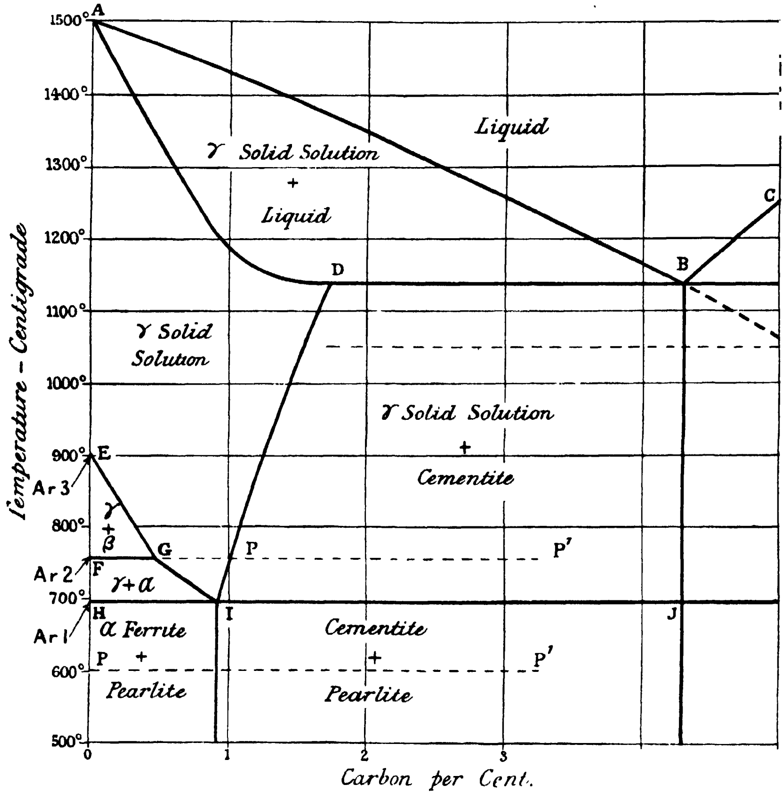


Fig. 7.—*Thermal observations in the Equilibrium Diagram of the Iron-Carbon Alloys.*

Compiled from data by Carpenter & Keeling (

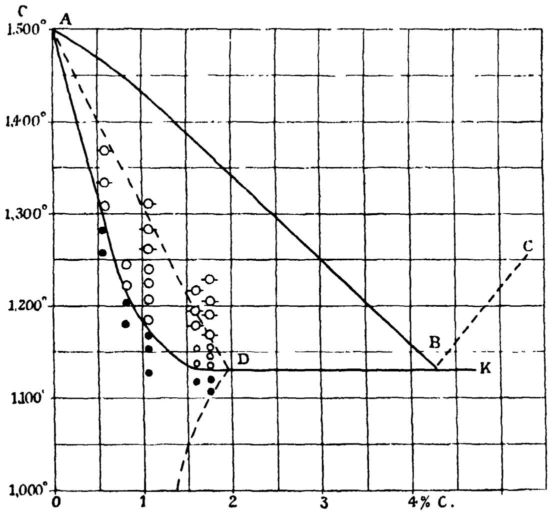
I now pass on to the equilibrium diagram of the iron-carbon alloys, and first I have prepared a figure, Fig. 7, which gives the facts without any interpretation or inference; on this figure the observed temperatures of heat-evolutions as found in the cooling-

Fig. 8.—*Equilibrium Diagram of the Iron-Carbon System*, 1911.



curves of iron-carbon alloys are inserted. The dots represent the observations of Carpenter and Keeling, but these are in the closest agreement with the earlier work of Roberts-Austen as shown in Figs. 1, 2, and 3 (page 246). In the next figure, Fig. 8, these observed facts are interpreted so as to yield an equilibrium diagram; lines and curves are drawn through most of the observed points, thus offering an explanation of the nature of those heat-evolutions. Two exceptions are shown by the dotted lines marked PP′. As regards the first of these, no very satisfactory explanation has yet been offered, so that they are left without explanation in this diagram; while as regards the second series, I have shown, some years ago, that they are not due to iron or steel at all but arise from an extraneous cause, so that we may omit them entirely from further consideration.

Fig. 9.—*Upper Portion of the Iron-Carbon Diagram.*



We will first consider the upper portion of the equilibrium diagram embracing the lines of Fig. 8 and shown in detail by the full lines in Fig. 9. This portion of the diagram deals solely with the manner in which iron-carbon alloys solidify from fusion, and it will be seen that the V-shaped upper or "liquidus" curve is very similar to that of our simple system of binary alloys, Fig. 6 (page 249), but one difference is at once to be noted; in the case of most alloys the equilibrium diagram extends from a concentration of 100 per cent. of one of the components right across to a concentration of 100 per cent. of the other component. In the iron-carbon alloys this is not the case, for the simple reason that there is no means of preparing these alloys with a carbon-content much greater than 6 per cent., so that our diagram only deals with the alloys near the iron end of the series, viz., those containing up to 6 per cent. of carbon only. Further, as these Lectures are to deal only with steel, our interest in the diagram is principally confined to the region of the alloys containing less than 2 per cent. of carbon. However, within the region of alloys containing less than 6 per cent. we have a liquidus curve A B C having a typical V shape; above this curve, that is, if the composition and temperature of any iron-carbon alloy is such that its place on the map or diagram falls above the liquidus curve A B C, the alloy is completely liquid. Along the branch A B of this liquidus curve the alloys begin to solidify by depositing crystals of iron in which a certain amount of carbon, or rather of carbide of iron, remains dissolved after solidification, while along the branch B C of the liquidus the alloys commence to deposit crystals—not of carbon, but of a definite iron-carbon compound Fe_3C, although at times this compound is liable to undergo immediate decomposition into iron and free carbon in the form of graphite. This, however, is a process with which we are not concerned in speaking of steels; we have merely to note that the line D B K indicates the freezing of a true eutectic—a eutectic of iron and carbide of iron. This eutectic line, however, unlike the one in our simple binary system, does not extend right across the diagram but ends at the point D where the "solidus" curve takes an upward sweep until it reaches the point A, the freezing point of pure iron. The reason why this eutectic line stops short in this way lies in the fact, which I have already mentioned, that the crystals which separate out from the molten alloys along the line A B are not crystals of pure iron but crystals of a solid solution of iron containing carbide of iron. So long as the amount of carbide present is smaller than that which the iron can retain in solid solution, no carbide will be left over after the solidification of the solid-solution crystals, and therefore there can be no eutectic formed—the residual liquid can never reach the composition of the eutectic. The point D, where the eutectic begins, corresponds to the saturation point of the solid solution at that temperature—slightly more carbide is present than the solid iron can dissolve, and this residue forms the eutectic.

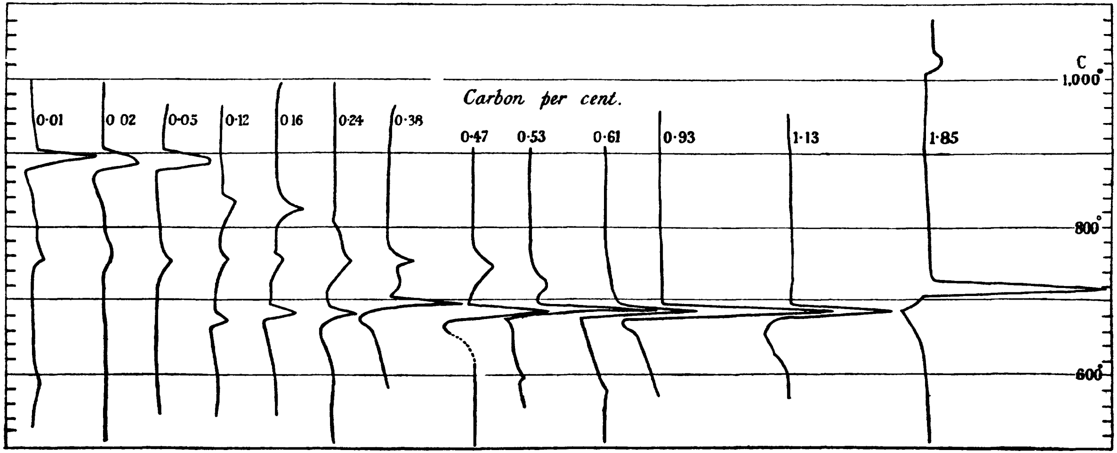
We have now to consider the curved portion of the "solidus," the line A D. This represents the temperatures at which the alloys have just completed their freezing process, that is, have just become completely solid, or, conversely, it represents the temperature of incipient fusion on heating. In the earlier investigations, and even in those of Messrs. Carpenter and Keeling, these temperatures were obtained by estimating the point on each of the cooling-curves where the heat-evolution due to solidification came to an end. Unfortunately the *end* of a heat-evolution is never sharply indicated on the curves, so that this estimation was admittedly vague. Quite recently that determination has been repeated, and with considerably greater accuracy, because a very much more satisfactory method was available. In order to describe it, I must forestall what I have to say a little later about microscopical examination of metals, and ask you to assume at this point that it is possible by means of the microscope to obtain an image of the internal structure of pieces of metal.

The method of determining the "solidus" was to take small pieces of steel, of known composition, heat them, and suddenly cool them from successively higher temperatures; afterwards each specimen was examined by means of the microscope. It is easy, as the photographs show, to determine what is the particular point at which you have reached a temperature where there was a small quantity of liquid metal present at the moment of quenching. Fig. 10, Plate 5, shows the structure of a steel containing about 1·76 per cent. of carbon which has been quenched from a temperature of 1,120° C. (2,048° F.). It represents a steel which was completely solid at the moment of quenching. There is no sign of liquefaction having taken place. But the next photograph, Fig. 11, shows a specimen of the same steel quenched from a higher temperature—a temperature of 1,170° C. (2,138° F.), and there are a number of "fusion spots" present, which show a structure typical of molten steel that has been caused to solidify very suddenly. Their typical appearance indicates clearly that this piece of metal had begun, and only just begun, to melt at the moment when it was quenched. The next two photographs, Figs. 12 and 13, refer to a steel containing rather less carbon. Fig. 12 is a steel quenched from 1,154° C. (2,109° F.), and there is another of these typical spots. The curious fish-shaped area is more highly magnified in the next figure, Fig. 13. This shows the structure typical of a suddenly solidifying metal. Figs. 14 and 15 refer to a steel containing just over 1 per cent. carbon; in Fig. 14 we have it quenched from 1,128° C. (2,062° F.), completely solid; there are no signs of fusion, but the next figure shows the same steel quenched from a temperature of 1,150° C. (2,102° F.) and here fusion is evident. Next we have a fairly mild steel, containing 0·57 per cent. carbon; and here, Fig. 16, Plate 6, again is a typical "fused" structure. In that way, by plotting the temperature at which signs of fusion were definitely seen, Gutowsky obtained the solidus curve which is shown by the full line in the diagram of Fig. 8 (page 252).

Gutowsky's results are more fully shown in Fig. 9 (page 253), where his quenching experiments are plotted; in this figure the circles with a line through them indicate that there was evidence of much fusion and that it was possible by examining the specimen to see that the outer edges were rounded; where there are circles only there were signs of liquid under the microscope, while the solid dots indicate that there were no signs of fusion. By means of the observations thus plotted, it is possible to draw a curve representing the temperature of the final solidification, or of incipient fusion on heating. The dotted line of Fig. 9 represents what was formerly accepted as the solidus, and on comparing this with the full line the importance of the new work is easily realized, because in the case of a 1 per cent. carbon steel, for instance, the temperature of incipient fusion is now found to stand at 1,180° C. (2,156° F.), whereas formerly it was regarded as being well over 1,300° C. (2,372° F.). When we remember the fact, and I think it is a definite fact, that a steel which is heated to a temperature of incipient fusion is definitely "burnt," and cannot be restored to a satisfactory condition except by re-melting, the importance

Fig. 17.

Cooling Curves of Carbon-Steels replotted from the data of Messrs. Carpenter and Keeling.



of knowing the temperature of incipient fusion is evident. And that knowledge has been obtained by means of the pyrometer and the microscope, in the way I have described.

We now turn to the lower part of the Iron and Carbon equilibrium diagram. This is again determined by the results of cooling curves, but this time they are not taken up to the temperature of fusion at all; we are dealing entirely with the phenomena which occur in the metal long after it has solidified; and all these cooling curves are taken by raising the temperature of a piece of steel well over 1,000° C. (1,832° F.), and watching its cooling. The cooling curves shown in Fig. 17 are taken from the work of Carpenter and Keeling, but they have been replotted for this figure by a method of my own so as to make them more easily understood; they now appear in the form known as "derived differential" cooling curves. The composition of each specimen is placed above its cooling curve; they range from nearly pure iron at one end to a steel containing something like 2 per cent. of carbon. There are a large number of peaks or arrest points clearly marked on these curves, and it is possible to plot them all together on a single diagram. This is shown in Fig. 18. I had occasion myself, comparatively recently, to take a number of these curves over again, and in order to show the close agreement between the work of independent observers, I have plotted my own results in the form of crosses, as compared with Carpenter and Keeling's, which are indicated by circles. In most instances the agreement is extremely close. The circles and crosses are the facts, the lines are the inferences.

In order to understand what those inferences are, and what they are based upon, we must consider the cooling curve of the end member of this series, that is to say, pure iron. Fig. 19 shows the cooling curve of pure iron as a diagram, because it is very rare to take any single one of these cooling curves over the whole range of temperature from the melting point of the iron downwards. The curve shows the first arrest at 1,500° C. (2,732° F.), where this iron solidifies from fusion; then it cools steadily until it reaches a temperature just below 900° C. (1,652° F.), and then there is again an evolution of heat; after that it cools steadily until the temperature has fallen to 750° C. (1,382° F.), where there is another smaller evolution of heat which sometimes occurs in two stages; after this, the iron cools uniformly. These are the facts, and the theory must now be considered. What is it that can happen in a pure metal to give rise to a powerful evolution of heat at a certain temperature long after the metal has become solid? It must be some change in the crystals, the molecules, or the atoms, which change liberates a certain amount of latent heat or energy. We are acquainted with such changes in other substances. We know, for instance, that oxygen exists both as oxygen and as ozone. We know that the element selenium exists in two or three forms; we know sulphur in three distinct modifications, which evolve heat and give out energy in their transformation from one form into the other. We are accustomed to meeting with carbon in the form of graphite, in the form of the diamond, and in charcoal, that is, amorphous carbon. So it is not surprising to find a metal which can exist in several distinct conditions. Those

Fig. 18.

Lower Portion of the Iron-Carbon Diagram.

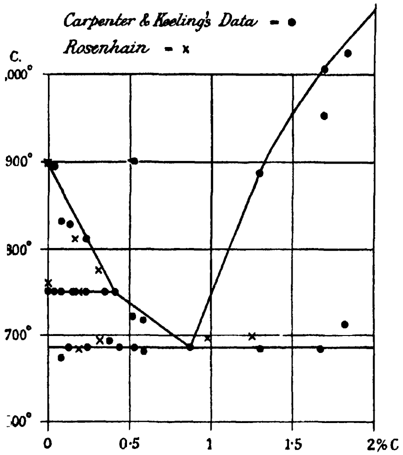
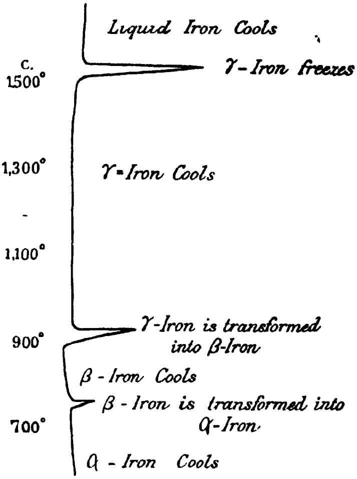


Fig. 19.

Cooling Curve of Pure Iron.



conditions are usually referred to in the case of these other substances as allotropic modifications. And therefore it is justifiable to say that these evolutions of heat indicate that iron also exists in three distinct allotropic conditions. The question is: what are the properties of these three kinds of iron, usually called Gamma, Beta, and Alpha iron? How do they differ from one another? Do they differ as much from one another as does graphite from the diamond, or as rhombic sulphur differs from the monoclinic? We have first of all one very striking fact—one striking difference between the iron lying above the temperature of the point Ar2, and that lying below, Fig. 19, that is, between Beta and Gamma iron and Alpha iron; and that is the fact observed by Gilbert in 1600 that iron becomes non-magnetic at a temperature above that point. Above this temperature it undergoes a profound modification; and one can almost say it is as great a change as anything we know in allotropic modifications in other elements. It is, however, interesting to look for other differences between these kinds of iron, and a number of investigators have worked at this question. We cannot examine iron under the microscope while it is very hot; at least, although it has been found possible to do this experimentally, there are certain reasons why it does not lead to fruitful results.

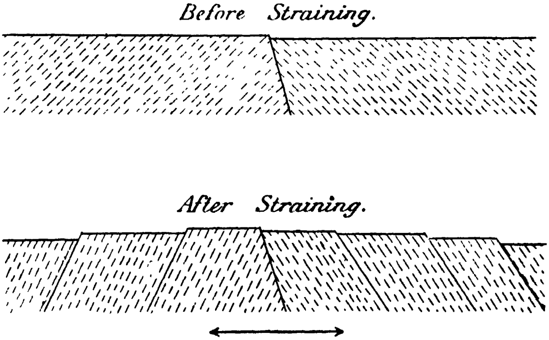
Osmond and Cartaud worked out the crystallography of iron at different temperatures, and were able to show small distinctions between these kinds of iron, but they were not very striking. Therefore, I wish now to show you the results of a piece of work which was done a little more than a year ago at the National Physical Laboratory by Mr. Humfrey and myself. We were fortunate enough, without in the first instance looking for them, to find a striking series of differences between the three modifications of iron. To explain this investigation the aid of the microscope is necessary, and first of all I must briefly call your attention to the manner in which metals are examined under the microscope.

It is now a fairly familiar fact that for this purpose the surface of a specimen of metal is polished, until it appears featureless and free from scratches under the microscope. The polished surface of the metal is then attacked by chemical agents which cause a differential action upon the different constituents, or if there is only one constituent, a differential effect upon its various crystals. This differential solvent action develops a surface pattern, which exists in relief or intaglio, and this may be aided by the deposit of films of some adherent precipitate. The pattern so produced can be examined under the microscope, and it has been found by exhaustive experiments that this pattern represents the actual structure of the metal beneath; it has a definite connection with that structure as it existed at the moment when the chemical attack or "etching" process was carried out. In pure iron, or nearly pure iron, we find the kind of structure which is seen in Fig. 20, Plate 6. Here is the structure of ordinary approximately pure iron taken from a specimen of transformer sheet iron of good quality; it consists of a number of roughly polygonal areas. Each of those areas represents the section of a crystal which has grown out from the centre, but which has not been able to develop itself to the full, in the way it would do if it had grown freely in a liquid. It has only been able to grow until it met its neighbours and so was limited by them, this limitation having prevented further growth. The boundaries of these crystals therefore lie where these growths have met one another. This is better seen if the specimen is etched more deeply; it is then possible to develop the texture of the crystals depending on their orientation. This is shown in Fig. 21, also taken from nearly pure iron. The differences of brightness on the various crystals of this figure are due to the fact that the acid which has been used as the etching reagent "unbuilds" these crystals in such a way as to leave on their surfaces a series of facets all facing the same way throughout each crystal. Consequently, since the facets on one crystal are turned so as to throw light which falls upon them away from the microscope, while those on other crystals reflect light into the microscope, these differences of brightness result. If such a specimen is illuminated in a different way, by a beam of light thrown obliquely upon the specimen instead of being sent down the tube of the microscope, these conditions of brightness can be reversed. The kind of picture thus obtained is shown in Fig. 22, representing the same portion of the specimen as Fig. 21. The cause and meaning of this light effect can be shown definitely by higher magnifications of these etched surfaces. Fig. 23 is an example in lead, in which the crystalline structure of lead is shown in much the same way as the structure of iron; only whereas in iron there was a magnification of 150 diameters, here there is only a very slight magnification. The structure is very large, and the manner in which the etching reagent has roughened the surfaces and developed facets on them is clearly seen. Fig. 24 shows the facets on a larger scale, from a sample of silicon steel, which has been photographed by Mr. Stead.

This inner structure of the crystals can also be shown in another way. Fig. 25, Plate 7, is taken from a specimen of cadmium which has been allowed to solidify in contact with a smooth polished surface, and some open cavities have been formed by minute air-bubbles which were imprisoned. They formed negative crystal bricks built into the mass of the other crystal bricks, and when the specimen was removed and examined under the microscope —the surface having never been touched by the human hand —it had the appearance shown in Fig. 25, when examined under a high magnification (1,000 diameters). The central crystal shows hexagonal cavities, while the adjacent ones show different shapes. We may now take a further step and ask, admitting that metals are crystalline in this way, what happens to the crystals if the metal is strained or stretched? What happens in that case is indicated diagrammatically in Fig. 26, which represents a section through two adjacent crystals of metal. The dotted lines represent the cleavage planes of the crystals. Under strain, the various crystal elements forming each of these crystals slide over one another. The crystal accommodates itself to the strain very much as a heap of books might accommodate itself by simply sliding in layers. I shall not trouble you with the evidence in proof of that wide statement, as it would lead me too far from my present subject.

When the traces of this slipping process are looked for under the microscope, they appear as fine black lines, and are known as slip-bands. Fig. 27, Plate 7, shows a specimen of an approximately pure iron, simply etched. These same crystals will be recognized again in a somewhat different condition in the next figure, Fig. 28, which is taken from the same specimen after forcibly stretching it to the extent of some 10 per cent. The crystals, although still there, are cross-hatched by numerous dark lines, which were not there before. These lines are the surface outcrops of these slips; they are like geological "faults," except that they are excessively minute. The next figure, Fig. 29, shows the same kind of slip-lines or "slip-bands," but under a higher magnification, again showing the appearances of these lines in ordinary iron. It will be noticed that the lines are far from straight; they are broken, forked, and curved, and I will ask you to bear in mind the more or less irregular character of the lines in this metal. For the purpose of comparison, we may take the slip-bands in lead, for instance, shown in Fig. 30, Plate 8. Here the lines are so beautiful and regular that they might have been ruled with a drawing pen; and one can recognize the stepped character of the slip-surfaces by the way in which the lines cross one another. An example of another metal, 25 per cent. nickel-steel, is shown in Fig. 31. The lines are almost as straight and regular as they were in lead, and strikingly different from what they are in ordinary iron. The next figure, Fig. 32, shows them in copper, and here also they are straight; but there is

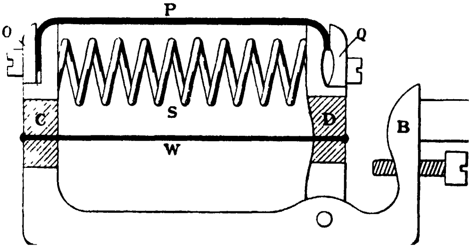
FIG. 26.—*Section through two adjacent Crystals of Metal.*



a peculiarity about them, for they have a regular angular deflection, recurring at intervals. And that is a sign of what mineralogists call "twinning," where certain portions of a crystal assume an orientation different from that of the rest, but in a symmetrical position relatively to it, and the slip-bands follow that change.

Now it occurred to Mr. Humfrey and myself that it would be interesting to enquire as to the cause of the difference in the slip-bands in iron, as compared with those of other metals; and it also occurred to us to consider whether, if these slip-bands were produced by straining the metal, not at ordinary temperatures but at a high temperature, these slip-bands would preserve their irregular character, or whether they would change with the allotropic modifications of the iron. And we proposed to try the experiment. The difficulty is, that the surface must be polished before the metal is strained, and this polished surface must be preserved from mechanical or chemical injury while the strain is being applied. To do this at a high temperature, say 1,100° C., presents considerable difficulties. The straining had to be done in a high vacuum, a vacuum considerably higher than that of an ordinary incandescent lamp. The way in which it was done is shown by the diagram in Fig. 33 which represents the apparatus we used. This consists of a small iron frame, with a fixed arm C, and a hinged arm D. The specimen is a strip of sheet steel P, which is fastened at O and Q. The hinged arm is forced away from the fixed arm by a powerful coiled spring S. The force of that spring is, however, resisted by a thin steel wire W which is

FIG. 33.—*Apparatus for observing Slip-bands.*



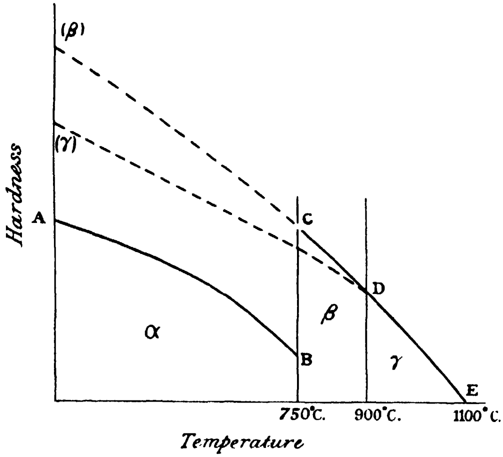
wrapped round the two arms and opposes the force of the spring, so that at first there is no strain on the specimen of metal. By suitable electrical connections it is possible to raise the specimen P to the desired temperature, by passing a powerful current through it; and when the desired temperature has been reached, the spring can be released by means of another electric current fusing the thin wire. The whole apparatus was small enough to be placed inside a glass flask, which could be highly exhausted, and therefore it was possible to use a piece of polished metal and to strain it and break it with this apparatus in a high vacuum, without allowing the surface to be tarnished in any way. And when we did this, we met with an astonishing result. It is a universal law, I think, in all metals, that as they get hotter they become weaker; and one would have expected this specimen of metal to break in the middle, because the comparatively big masses of iron at the two ends tended to cool the portions of the specimen adjacent to them, and it was only the middle of the piece of metal which reached the full temperature. But the strips of iron or steel broke, not in the middle, but at one of the outer thirds. When we examined the change under the microscope, we discovered the reason. It was found in our later experiments that by putting on the back of the specimen small fragments of salts of various melting-points, we could ascertain the approximate temperature at which the break took place. The temperature of the iron was 1,100° C. or 1,200° C. (2,012° or 2,192° F.) in the middle, and it fell to a dull red heat at the ends; and we found that the fracture always took place at a point where the temperature was between 700° and 800° C. (1,292° or 1,472° F.). Now 750° C. (1,382° F.) is the temperature of the critical change, the $\alpha \rightleftharpoons \beta$ change in iron. And when these specimens were taken out and examined under the microscope, we saw what had happened.

I may say we worked on the purest iron obtainable, and we began by observing what happened when it was heated *in vacuo* without straining it. Fig. 34, Plate 8, shows the sort of effect obtained; a system of crystal boundaries is formed, probably by some of the crystals protruding themselves beyond others. That is a sign of some profound changes occurring, but in the hotter portions of the specimen there are gases given out by the steel which slightly attack the surface; and the darkened areas in Fig. 34 show the characteristics of what we know as the "gamma" condition of iron at very high temperature. We will now examine the effect of strain. Fig. 35 represents a portion of a strained specimen. On the left side there is a very typical appearance of severely strained ordinary iron—iron as it would appear at the ordinary temperature, "alpha" iron, as we call it. But the interesting fact is, that all this appearance of α-iron slip-bands ceases abruptly along one particular line. In the photograph the magnification is 100 diameters, and over a very short range—about $\frac{1}{100}$th of a millimetre of the specimen—we pass from the region of severe strain into a region of practically no strain at all, although the temperature of the specimen was rising from left to right. That is a sign of a very profound change in the iron; a stress which has been sufficient completely to break the metal on the left of this line is insufficient even to strain it on the right. The metal has undergone a change, and has become harder and stronger, in spite of the rising temperature. And that abrupt change is associated with the temperature at which the "alpha-beta" transformation occurs in the iron in the cooling and heating curves.

If we pass into the hotter region of the specimen, we find the appearance shown in the next figure, Fig. 36. There are numerous slip-bands in these crystals, and there is a beautiful example of that characteristic twinning which was seen in the slip-bands of copper. This is not observed in cold iron. At the point where this photograph was taken we have passed into a region where the iron was not so strong as the metal immediately after the first change; but here the slip-bands have adopted the regular characteristics found in other metals, such as lead and nickel-steel. The analogy with nickel-steel is particularly strong; in fact, we have in both iron in the "gamma" condition showing characteristics utterly distinct from those of the original "alpha" iron and different from the intermediate "beta" iron, which appears to be harder and stronger. The metal with which these experiments were made was transformer sheet, containing a small proportion of silicon and other impurities. Afterwards the experiments were repeated with pure electrolytic iron; and Figs. 37 and 38, Plate 9, show the same phenomena again. In this material the crystals are comparatively large. In Fig. 37 it is seen that there is severe strain on the Alpha side, and an absence or almost an absence of strain on the Beta side; there is a sharp transition from one to the other; there are the characteristic wavy forked slip-bands on the Alpha side, and not on the other. The next figure, Fig. 38, shows the Gamma-iron region in electrolytic iron, and the characteristic twinning bands are very prominent. This photograph is very similar to the appearance of annealed high nickel-steel, containing about 30 per cent. of nickel. For comparison, Fig. 39 shows the typical twinning in ordinary brass; the resemblance is evident at once, and such structures are characteristic of all metals which "twin" readily.

We may now sum up for a moment the facts and the inferences to be drawn from them. The facts are that there is an abrupt change in the mechanical properties of pure iron at a definite temperature, which is probably associated with the lower critical point. At still higher temperatures there is a further change to a condition in which the iron strongly resembles metals like brass and nickel-steels, which show much twinning. The first important inference we are justified in drawing is that iron preserves its crystalline character up to a temperature of at least 1,100° C. (2,012° F.), and this is a distinct step forward in our knowledge of the behaviour of metals at these temperatures; and the next inference which I think we are quite justified in drawing is that we have here mechanical effects representing the three allotropic conditions of iron which have been called by Osmond, Alpha, Beta, Gamma. The Beta-iron appears to be stronger and harder than Alpha-iron, although existing at a higher temperature. A strip of iron of uniform section will break in the hottest part of the region of Alpha-iron rather than in the region of Beta-iron, although the latter may be as much as 100° C. hotter. Now it is well known that in most metals—probably in all metals—hardness and tensile strength decrease rapidly with increasing temperature. From the experiments just described, it may be inferred that this hardness-temperature curve receives a step-up at the allotropic change—as indicated diagrammatically in Fig. 40. Now I think it is legitimate to say if by any means the allotropic form of iron can be preserved right down to the ordinary temperature, its hardness would attain a very high value, because we should be justified in prolonging the curve upwards as indicated by the dotted line. This inference must be considered on its merits. I think the facts justify it, and it has some bearing on the nature of hardened steel.

Fig. 40.—*Hardness-Temperature Curve.*



We return to the equilibrium diagram of the iron-carbon series. We have discussed the transformations which occur at the point E and the point F, Fig. 8 (page 252), in pure iron. How do they influence the decomposition of the solid solution which is formed in the region AEGID? That solid solution is formed by the solidification of molten iron containing carbon, without the separation of that carbon as a distinct constituent. I think I am justified in saying that the carbon is there not as carbon, but in the form of carbide dissolved in Gamma-iron—I shall speak in the language of the allotropic theory now. This γ-iron solid solution behaves as a liquid solution of two metals in one another would behave, that is to say, at one temperature it undergoes decomposition, and deposits crystals of one of its constituents. Along the branch EGI the crystals deposited are of iron; along the branch DI they are crystals of carbide of iron. This is a binary system of alloys, iron and carbide of iron. At the temperature of the point E there is a transformation in pure iron from the Gamma to the Beta condition, and the temperature at which this change takes place is depressed along the line EGI by the presence of carbide, just as in a liquid alloy of two metals there is a depression of the freezing point by the presence of another metal in solution. Finally, the decomposing solid solution reaches the temperature of the line HIJ, which corresponds to the eutectic line in the binary alloys, and it is then that the residual solid solution in this case undergoes its transformation. In the alloys the liquid solution solidifies; in this case it decomposes. There is, however, in the iron-carbon alloys the additional fact that there is another line of transformations FG where the Beta-iron, which is deposited along EG, changes into the Alpha form. Take the case of an alloy containing 3 per cent. of carbon. It cools steadily until it reaches the temperature of the line EG, in this case about 820° C. (1,508° F.). There the Gamma-iron begins to deposit crystals of Beta-iron. But Beta-iron has very little power of dissolving iron-carbide; therefore as crystals of Beta-iron are deposited, the residual solid solution becomes enriched in carbide. Therefore in the region EGF there is a mixture of β-iron and γ-iron solid solution, and this last contains the whole of the carbide of the alloy. On crossing the line FG the Beta transforms into Alpha, and perhaps some more carbide is deposited. Finally, when the alloy arrives at the line HI, the residual solid solution undergoes decomposition, and a constituent is formed which corresponds to the eutectic of the binary alloys—this is called the "eutectoid." It is a duplex constituent; it contains nearly all the carbon present in low-carbon steel. It is duplex because like all eutectics it consists of two constituents, as seen under the microscope.

We shall now consider the microstructures which result when these transformations have their way, when the steel has cooled sufficiently slowly to allow completion of these decompositions. In Figs. 20, 21, and 22, Plate 6, was seen the appearance of pure iron under the microscope, and in Fig. 41, Plate 9, we have the appearance of a steel containing about 0·07 per cent. carbon, that is to say, extremely little carbon. But that small amount has given rise to the presence of numerous dark patches. The crystals of the iron are still plainly seen; the variously shaded areas recall the shaded areas in the ferrite of pure iron as shown in Fig. 21. These areas represent the pure iron constituent as it appears under the microscope. It has received the name "ferrite." It is really iron, but the microscopical constituent is now called ferrite, which is an elaborate name for a very simple thing. The other constituent is due to the presence of carbon; it appears as dark patches occurring in the interstices of the ferrite crystals. This constituent has received the name "pearlite," the reason being that when it is examined in certain conditions of illumination it exhibits a mother-of-pearl iridescence, and that is why Sorby described it as the "pearly constituent" of steel. From that description the name "pearlite" has arisen, and has persisted.

It is important to notice that 0·07 per cent. of carbon, which is only seven parts in 10,000, gives rise to this considerable amount of pearlite. The reason is that the pearlite itself contains less than 1 per cent. of carbon, but the presence of that 1 per cent. of carbon is sufficient to make it etch or turn dark under the etching reagents, and reveal its presence in that way. The amount of it in any given steel depends on the composition of that steel, that is to say, the amount of carbon present in that steel, provided the other elements, particularly the manganese, are constant in the series.

We now pass on to some examples of steel containing more carbon. In the next figure, Fig. 42, Plate 9, is seen a steel with a higher percentage of carbon (0·18 per cent.). It is difficult, perhaps, to estimate the proportions from these photographs, because it is impossible to show on a single photograph a large area at once;

but when examining these things under the microscope one passes a considerable area of the specimen under review before forming a judgment. In Fig. 42 there are two distinct regions; on one side of the photograph we have the typical appearance of a steel with 0·2 per cent. of carbon, and there is also a band of almost carbonless iron; and it is an ordinary characteristic of steels to find that the carbon is not quite uniformly distributed. Of course these alternations may be repeated two or three times in a hundredth of an inch, so for most purposes the homogeneity is sufficient.

The next figure, Fig. 43, Plate 10, shows a higher percentage, 0·4 per cent. of carbon. The pearlite areas have become larger and more numerous, but the etching has not been carried far enough to show the ferrite crystals. Fig. 44 shows a similar steel which has been treated differently as regards heat. It shows the same kind of pearlite but a different arrangement. In the second Lecture I shall deal with the meaning of these laminated formations. Fig. 45 furnishes an example of a feature which is often found in these pearlite steels. The figure shows the structure of rolled steel as seen in longitudinal section. It has been rolled in the direction of the bands, and the pearlite has been elongated. If such steel is annealed, although the pearlite breaks up into a number of separate crystals, each of which is more or less symmetrical, yet they remain grouped in this particular banded way. There are some steels, particularly those which contain a certain amount of phosphorus, from which that structure is not removed by any amount of annealing. It is one of the most typical features of commercial steels. The next figures, Figs. 46 and 47, Plate 11, show examples of the structures of other steels consisting of ferrite and pearlite, the proportion of pearlite increasing with the carbon content. In some of these steels the structure has been made coarser by heating, and in these, particularly when highly magnified, it is seen that the dark constituent is not uniform, but is made up of ribs or bands of two distinct things, which appear light and dark.

If, for the purposes of analogy, we examine the structure of a copper-silver alloy consisting of an excess of silver embedded in the copper-silver eutectic, as shown in Fig. 48, Plate 11, we see how closely it resembles the steel shown in Fig. 44. Like the steel, the silver alloy shows white crystals embedded in a laminated matrix.

We come now to steel containing still more carbon. Here pearlite is found occupying practically the entire field. In Fig. 49 we have nothing but pearlite; this is steel containing 0·9 per cent. of carbon, and that is the composition of pearlite itself. Here the laminated structure is well marked, but it is shown still better in the next figure, Fig. 50, which has been taken under higher magnification and shows a very typical example. For comparison, Fig. 51, Plate 12, gives an example of the structure of the eutectic of the lead-tin series, where the characteristic lamination is well shown. Such examples could be multiplied indefinitely, but enough has been given here to show how close is the analogy. The lead-tin eutectic is formed by the decomposition of a liquid solution, while pearlite is formed by the decomposition of a solid solution. As regards the nature of a solid solution, we need only suppose that the condition of intimate mixture which exists in the liquid state has been retained in the solid state. In the solid state, the crystals of a solid solution are built up indiscriminately of the dissolved and the solvent substances, and such a solid solution decomposes very much like a liquid one, only, owing to lesser power of motion of the molecules in the solid state, the time occupied by the change is considerably longer. And it is possible to do one thing in the solid state which it is not possible to do in the liquid, namely, to prevent decomposition by sufficiently rapid cooling. But perhaps that is the only vital distinction between a solid and a liquid solution.

We pass on to steel containing more than the amount of carbon found in pearlite. We have come down to the point I on the diagram of Fig. 8 (page 252), where the steel consists entirely of pearlite containing 0·9 per cent. of carbon; and we come now to steels which begin by depositing crystals of cementite as they cross the line ID and complete their decomposition by depositing pearlite as they cross the line IJ. Fig. 52, Plate 12, shows the microstructure of such a steel; there are white typical crystals of cementite, while the rest of the field is pearlite. This is a steel containing about 1·2 per cent. of carbon.

The microstructures of steels containing still higher proportions of carbon are illustrated in Figs. 53 and 54, which relate to steel containing 2·2 per cent. of carbon. Here there are large quantities of cementite and some pearlite, but no ferrite whatever—just as the equilibrium diagram would lead us to expect. If these steels are annealed, so as to render their structure coarser, the cementite crystals attain a relatively enormous size, *see* Fig. 54, while the pearlite segregates into very coarsely laminated regions. In fact, this laminated structure of pearlite is incidental rather than essential—in both the eutectoid and also in eutectics derived from liquid alloys, the laminated structure is simply an incidental result of the manner in which the decomposition of the solution takes place—if the decomposition is caused to take place very slowly, or if the metal be kept for a long time at a temperature just below the decomposition point, then the laminated structure may be made to disappear entirely, each of the two constituents of the eutectic or eutectoid becoming massed together in comparatively coarse lumps instead of being finely divided as alternate lamellæ.

I have repeatedly used the term "eutectoid" in reference to pearlite—the word being slightly modified from the more widely used term "eutectic" in order to emphasize the fact that while the "eutectic" results from the decomposition (and solidification) of a liquid solution of two metals, the "eutectoid" results from the decomposition of a solid solution. Having adopted this term "eutectoid," it becomes convenient to speak of a steel consisting entirely of pearlite as a "eutectoid" steel, just as we speak of the "eutectic" of lead and tin, etc. Further, for steels containing less carbon than the eutectoid, and therefore consisting of ferrite and pearlite, the term "hypo-eutectoid" is often used—this term describes the whole range of steels represented by that part of the equilibrium diagram lying to the left of the point I, Fig. 8. For the steels lying to the right of this point, and—as we have seen—consisting of cementite with pearlite, the term "hyper-eutectoid" is used. Since these terms are in fairly universal use among metallurgists it is necessary to define them here, but I ought to add that Professor Arnold does not like these terms; he prefers to call the pure pearlite steel a "saturated" steel, and for "hypo-eutectoid" he uses "undersaturated," and for "hyper-eutectoid" he prefers "supersaturated." Personally, I prefer to adhere to the general practice, but it is chiefly a matter of words, since the real classification of the steel remains the same.

In the present Lecture I have tried to explain the varying constitution and properties of pure iron at different temperatures and the constitution and structure of slowly-cooled steel of varying carbon-content. The manner in which the structure and constitution of steel varies with the temperature and with the duration of heating and rate of cooling, I must leave to be dealt with in the next Lecture. But before concluding I wish to deal with one more point which, from the engineering standpoint, is most important, and that is the influence of pearlite and cementite on the physical properties of steel.

It is an almost universal law, to which there are few if any exceptions, that definite chemical compounds between two metals, and still more so between a metal and a metalloid, are exceedingly brittle. Now cementite is a definite chemical compound of iron and carbon, and as such is very hard and brittle. Pearlite, however, is a mixture of two things, those two things are lamellæ of cementite —iron carbide—and lamellæ of ferrite or nearly pure iron. The cementite lamellæ are hard and brittle, while the ferrite lamellæ are soft and ductile. Therefore pearlite, which is an extremely intimate mixture of the two, shares to some extent the properties of both—it exhibits a considerable degree of hardness, although far less than that of cementite, while it possesses a small share of the toughness and ductility of ferrite. In steels which consist of ferrite crystals having pearlite grains in their interstices, the hardness and stiffness of the pearlite exerts a strengthening effect—it acts as a sort of reinforcement to the soft and ductile ferrite. Consequently, with increasing pearlite we find an increased elastic limit, increased ultimate strength, increased hardness and decreasing ductility. So, with increasing hardness and stiffness we have a steadily decreasing ductility until the eutectoid composition—about 0·9 per cent. of carbon—is reached. Beyond that point—in the hyper-eutectic steels—we have a mixture of cementite and pearlite, and in this the hardness and brittleness of the cementite predominates, so that these steels are hard and brittle even in the annealed state. These relationships are illustrated diagrammatically in Fig. 55, Plate 13, where an approximate curve of tensile strength and hardness is plotted against carbon-content, while a series of photomicrographs are inserted to illustrate the structures typical of the various compositions. This diagram shows the direct connection existing between constitution, microstructure and mechanical properties.

TWO LECTURES ON STEEL.

By Dr. WALTER ROSENHAIN, of the National Physical Laboratory, Teddington.

Second Lecture.

Tuesday, 25th April 1911, at 8 p.m.

Professor William Gowland, F.R.S., in the Chair.

Mr. Chairman and Gentlemen,—In my previous Lecture I tried to give an account of the various constituents met with in carbon-steels when those steels are allowed to solidify and to cool slowly down to the ordinary temperature. The constituents of which I spoke were ferrite, that is to say the crystals of pure iron, or at least of nearly pure iron, which separates along the left-hand branch EGI of the equilibrium diagram shown in Fig. 8 (page 252). Next, there is the cementite which separates along the branch ID, and the eutectoid body, pearlite, which separates along the line HIJ. I spoke of the constitution and structure of a given steel as being dependent upon its chemical composition, that is upon the carbon which it contains. Now, provided all the steels are treated alike, it is perfectly correct to say that their structure depends only on their chemical composition; but the treatment which a particular steel undergoes makes all the difference to its microstructure, and it is to these differences that I wish to direct your attention to-night. Towards the close of my last Lecture I tried to indicate the mechanical properties of the various constituents of carbon-steels. There is, first of all, the soft, or at all events comparatively soft, ductile ferrite. Next, one finds the extremely hard and brittle cementite; and further, one has what may be called the intermediate character of the pearlite, which is an intimate mixture of these two. Now, the treatment to which steel is subjected most frequently of all in engineering, that is to say in practical use, tends—unsuccessfully in the majority of cases, but still the tendency is there—to break the steel. It is therefore interesting to see how the mechanical properties manifest themselves, and how the various constituents behave when that treatment is pushed to the point at which breakage occurs. Ferrite, consisting, as I told you, of pure or nearly pure iron, is a soft and ductile body; and, consequently, when tensile stress is applied to it, the crystals of that substance are elongated, they definitely draw out, by that process which I described last time as "slip." These elongated crystals ultimately tear across the cleavage planes upon which the "slip" which I have mentioned has been going on. The slip goes on in the way which I have tried to illustrate by the behaviour of a pile of books. Deformation takes place by the sliding of these crystal layers into new positions; and the time comes when this sliding reaches its limit, and separation occurs. Before that happens, these crystals, as will be readily understood, have been elongated to an enormous extent, so that they become almost rod-like in character and appearance. Now, the way in which these crystals behave when they are broken is best shown by means of a number of microsections taken from actual fractures. These were obtained by first of all embedding the broken end of the specimen in copper, which is deposited electrolytically. Such a deposit of a hard metal is necessary in order to prevent the cutting process from injuring the edge of the specimen. If one were simply to cut through the fracture itself and try to examine it under the microscope, it would not be possible to see the edge, because it would be rounded off in the cutting and polishing process; therefore this edge is protected with a deposit of copper and the section is cut through the composite mass; the section of the fracture appears as the boundary between the steel and the copper.

Fig. 56, Plate 14, shows a section which is typical of a silky fracture of very pure iron produced in tension. That silkiness is due to the fact that slipping has gone on to its greatest possible extent, but the fracture is essentially crystalline although the elongated crystals *appear* fibrous.

When we come to a body which consists not entirely of pure ferrite, not merely of iron, but contains pearlite, we have a ductile matrix which is reinforced by islands of pearlite. And these islands of pearlite serve to hold up the matrix of ferrite against the applied stresses for a considerable time. Hence the higher yield-point of steel of this character compared with that found in pure iron. But once that resistance is overcome, the ferrite begins to stretch by the process of slip, and plastic deformation sets in; for a time the pearlite grains are carried along bodily by the deforming and stretching ferrite crystals, but the pearlite crystals cannot stretch materially, and therefore when the process of carrying them bodily on has proceeded until it has reached its limit, these pearlite crystals begin to crack; the pearlite islands can no longer accommodate themselves to the stress without actual breakage taking place. When the islands crack across and fracture sets in, this fracture runs across the ferrite crystals and into these cracks of the pearlite. And the astonishing result which occurs in such a case is that in the tensile fracture of a mild-steel consisting of ferrite and pearlite, although the pearlite is very much stronger, the tensile fracture runs indifferently across both constituents. A section of such a fracture is shown in Fig. 57. The black areas represent the pearlite which has been darkened by somewhat deep etching. The character of such a fracture is more clearly shown in Fig. 58. This represents a pearlite area near the fracture, and a crack can be seen running into it—this is very highly magnified and shows the laminated structure of the pearlite. That, or something very like it, is quite a common appearance in all tensile fractures in the case of mild-steel. On account of its comparative brittleness, pearlite breaks when a certain degree of deformation has taken place, and the fracture runs from these cracks in pearlite into and across the ferrite.

The fractures just described were produced by slowly applied tension, accompanied therefore by a considerable amount of plastic deformation, and the metal has been stretched considerably. Now let us look at another kind of fracture; let us take shock-fracture. If we break a specimen off, not by tension but by a sudden blow, then the ferrite behaves in quite a different manner. Whereas in the one case, where there was a steadily applied force, this soft constituent undergoes deformation by the process of slip on the cleavage or gliding planes, under a suddenly applied force or shock it breaks across the cleavage planes. The analogy of the books serves again to illustrate the sliding which occurs; under shock there is a bodily breaking across by one act; there is no previous plastic deformation set up. The pearlite carefully isolates itself from the shock, and the failure takes place through the well-developed cleavage planes of the ferrite. The next two figures, Figs. 59 and 60, Plate 14, illustrate this clearly. Fig. 59 is the fracture of a piece of wrought-iron; it is a shock-fracture, and shows a section of the large crystal facets which appear on such a fracture. These facets do not quite correspond with the crystals themselves as shown by the microstructure, but in this specimen the cleavage passes almost undisturbed through whole groups of crystals; it was for that reason that this particular piece of iron was very brittle. Fig. 60 shows the shock-fracture of mild-steel. That fracture has carefully skirted all the pearlite; there is only one place where the fracture passes through the pearlite, in most places there is a little rim of ferrite round the pearlite. The fracture has followed the easy cleavage planes of ferrite, and has avoided the harder, although in many ways more brittle, pearlite almost entirely.

We have now to deal with another kind of fracture—that which results from failure under fatigue or alternating stresses. The typical feature of such failures is that they occur under the repeated application of a stress which if applied once only, or continuously, would not have led to breakage. For a long time this proved a very puzzling phenomenon, but thanks to the investigations of Professor Ewing and Mr. Humfrey, since confirmed by the work of Dr. Stanton and Mr. Bairstow, a satisfactory explanation of the whole question is now available. The explanation is really very simple.

Earlier in these Lectures we have seen how the deformation of a piece of metal takes place by a process of slip occurring on the cleavage or gliding planes of the individual crystals of which the metal is built up. Now when a stress is applied to a piece of metal, that stress may be quite insufficient to produce any definite plastic yielding of the piece as a whole, but if the stress is not very far below the yield-stress, then here and there in the mass a crystal will be found which happens to be particularly unfavourably situated with regard to the stress-distribution and so may receive more than its fair share of the burden, and such individual crystals will yield a little under the load—always by this process of slip. If the stress is left in continuous operation this process of adjustment will soon come to an end, and if the stress be removed and not again applied for a considerable time, such as several hours or days, the effect upon the metal will be almost nil—a very slight local change in texture at the points where the local yielding had occurred being the only result. But if the stress is reversed immediately after its application, it finds the crystal which had undergone the slight local yielding in a particularly weak condition, and the result is that this same crystal yields again, but in the reverse direction—the slip is simply reversed, and a reverse motion occurs over the same gliding plane as before, and this reversal continues with every reversal of the stress. Now it has been shown by Beilby, first in connection with the behaviour of surfaces subjected to rubbing or polishing, that such a rubbing process loosens the molecules from their crystalline arrangement for the time being. If the sliding and consequent grinding process is continued, this molecular disintegration will also continue and the resulting amorphous matter, in its temporary mobile condition, will be forced out between the sliding surfaces. In that way the original surface of slip becomes an actual fissure. The moment this occurs, that crystal ceases to bear the burden which falls to its share, and as a consequence extra stress is thrown on the adjacent crystals so that they yield and the fracture spreads rapidly. When the breakage occurs, the fracture shows crystal facets which are really the surfaces upon which this sliding or grinding action has been taking place, and these are spoken of as crystalline fractures. They are, as a matter of fact, no more and no less crystalline than others, but they exhibit this crystalline appearance. In Figs. 61 to 64, Plate 15, are seen examples of some of the actual phenomena which are found in microsections of metals which are exposed to alternating stresses.

The experiments represented in these Figures (61 to 64) were made upon a rod of Swedish iron which was loaded as a cantilever and rotated so as to expose it to alternations of bending stress—one reversal for each revolution. This is the well-known Wöhler experiment. Now, on the surface of such a rod at the end where the maximum stress occurs, we must suppose a small area to be polished and etched for microscopic examination. At first such an area shows simply the polyhedral crystals, without any slip-bands, but after 2,000 reversals of a stress of about 12·4 tons per square inch a few lines begin to appear, as shown in Fig. 62. After 10,000 reversals the lines appear both more numerous and much wider and thicker, Fig. 63, and after 40,000 reversals the stage is reached which is represented in the last of the four photographs shown, Fig. 64. In the earlier stages of this process, while the lines are simply the surface traces of slip, if the surface is repolished the lines disappear entirely, but in the later stages repolishing fails to remove them—we are no longer dealing with mere surface features but with actual fissures—and close upon that stage follows fracture, under a stress which would not have broken such a rod if applied continuously.

From those observations there are two important conclusions to be drawn. One of the conclusions which I think I am justified in asking you to come to is, that you should discredit the idea that vibration or alternating stress tends to render iron or any other metal crystalline. It is crystalline to begin with; it is of no value as a metal unless it is crystalline, and no treatment short of the severest cold-working of iron or steel at the ordinary temperature will alter the condition of the crystals of the material. If the metal is subjected to alternating stresses and vibration so as to produce fracture, that fracture has a crystalline appearance, but that is due to the causes I have described, and *not to any change in the internal structure of the metal.* The second conclusion which I think I can ask you to draw is this. The specimen illustrated in Fig. 61 is one of nearly pure iron, and the disintegration by slip is a phenomenon which occurred entirely in the ferrite. In a steel which consists partly of pearlite and partly of ferrite, this action is impeded because the production of these fissures is impeded by pearlite; they have to go round it, consequently the resistance of carbon-steel is proportionately distinctly higher than that of pure iron. And from the point of view of the resistance of the metal to alternating stresses—I am not speaking of the resistance to shock—from the point of view of the resistance to comparatively steadily applied alternating-stresses the higher the carbon-content, up to 0·9 per cent. of carbon, the better the resisting power of the metal. There are countervailing considerations in designing the moving parts of machinery, where frequently a considerable degree of ductility is required in the metal; but purely from the point of view of resistance to alternating stresses, the more pearlite the steel contains the higher will be its power of resisting alternating stresses.

We have now to consider the various forms of mechanical treatment often applied to steel. In the workshop one is constantly handling metals in a cold condition, and imposing stresses upon them for the purpose of altering their shape, and the question which arises is, whether such treatment is legitimate and right? We may see the effect on the ferrite of deformation in the cold, by taking a piece of iron and squeezing it so as to flatten it somewhat. Fig. 65 shows the effect on the ferrite crystals produced by a fairly severe mechanical deformation of that kind. The crystals all lie in one direction, and such a material has very much altered properties. The process of slip has taken place to a considerable extent and it has rendered further slip more difficult. The material has been hardened and made more brittle by this process; and if a piece of metal is treated in that way and we rely upon its ductility, we should be relying upon a broken reed and very likely also upon a broken piece of metal. In practice, one constantly sees cases of failure from causes of this kind, and one finds this kind of thing not only in pure ferrite, but also in carbon steel. Fig. 66 shows the result of another kind of mechanical treatment which has brought about a considerable amount of deformation. In this Figure, Fig. 66, there is a seriously deformed steel, but this is the result of the action of a cutting tool. This figure illustrates the fact that our ordinary cutting tools are implements for applying breaking stresses to metal; they act by means of forces locally concentrated on the surface which we propose to cut; we can in fact only cut by breaking the metal locally; and if that breaking is done rapidly and vigorously, in other words at a high speed, with high-speed steel, while actual breakage occurs only at one point, severe deformation and injury penetrates for a short distance into the metal. Where this cutting strain is severe, a skin of seriously strained structure is left, and the consequent brittleness of that skin must be reckoned with.

Fig. 67, Plate 16, shows carbon-steel which has been treated in much the same way as the ferrite shown in Fig. 65; the pearlite and ferrite areas are pressed out into long narrow rods. That particular specimen has a history which is somewhat tragic; it is a piece taken from a boiler which exploded, with disastrous consequences. The explosion was due to the fact that certain portions of the boiler had been forcibly treated mechanically in order to make them fit where they would not fit easily, and this had been done by means of a machine which produced in certain areas this severe deformation of the steel. Ultimately at that point the steel cracked, and the vessel finally burst, with disastrous consequences. So that the consideration of these deformations in steel resulting from stresses applied when cold is a very serious matter in workshop practice.

I must now pass on rapidly to the consideration of the effect produced on steel by heat. At the beginning of this section of our subject the fact must be recognized that the component crystals of any metal manifest a strong tendency to grow, that is to say, to increase in average size, and at the same time to decrease in numbers. The real cause of this tendency is that there is a store of potential energy in the crystal boundaries, and like all potential energy in the universe, this tends to run down. This is done by the joining together of crystals, with a resulting decrease of the area of boundary and of the energy stored in those boundaries. Thus there is a powerful cause at work tending to reduce the number, and at the same time to increase the size of the crystals which constitute the substance of a metal. At the ordinary temperature, in such hard metals as iron and steel, this tendency is held in check by the molecular rigidity of the material; the molecules cannot move freely, and the potential energy cannot find its way down, and so the tendency for crystal growth is held completely in check. In such soft metals as lead, and even in brass in certain conditions, this growth of crystals can be traced. At the ordinary temperature in iron and steel, and particularly in ordinary slowly-cooled iron and steel, I do not think that any changes occur at the ordinary temperature; but at temperatures from red heat to white heat, this tendency is given full play. The crystals tend to grow with amazing rapidity. It may be asked, from a practical point of view, what does it matter? I answer, it matters this much, that the value of a metal from the mechanical point of view is dependent upon the size of the crystals in its microstructure; the smaller that structure, the less well-defined the individual crystals, and the less well-separated the constituents, the better from the engineering point of view; and any tendency to allow those crystals to develop, will not only allow them to grow in size, but will permit them to develop their crystalline character more fully, and their cleavage planes will become more developed, and shock-fracture will become increasingly facilitated as this growth proceeds. Therefore I would say, avoid heating metals beyond the point which is really necessary. That is, of course, a wide rule, which cannot always be followed in practice, and there are considerations which make it possible to heat metal without going beyond the weakening point, but in general terms it is always desirable to avoid heating metal beyond the absolutely necessary temperature.

There are two kinds of check upon this growth of crystals. We have followed by means of the diagram of Fig. 8 (page 252) the changes which steel undergoes in passing through certain critical temperatures. Those changes have a bearing upon the scale and character of the microstructure in this way—that when, for instance, Gamma-iron crystals are transformed into Alpha-iron crystals the transformation does not occur simultaneously over the crystals as a whole, but commences at a number of points. Therefore from each such individual point as a centre the transformation goes on until the whole mass is occupied. Wherever coarse crystallization existed before, the transformation supplants it by a new system of crystals. That process is illustrated very well in Fig. 68, Plate 16, which has been taken from a piece of very mild steel by Mr. Stead.* This steel was heated to 1,000° C. (1,832° F.) at one end and kept moderately cold at the other. It has been etched but it is not magnified, and the large size of the crystals which have formed will be noticed at once. At the temperature of the critical point there is a transition to a fine structure; but if we had a piece of steel with this coarse structure and we tried to refine it, to make the structure fine again by heating it up through the critical point, and wished to rely upon this re-arrangement of structure, we might easily fail, because it has been found that although there is this re-arrangement, the whole structure tends to revert to the original condition on passing back to coldness. One can take a piece of steel and photograph its microstructure, and heat it up to a red heat and then cool it down, and yet find nearly the same microstructure again, unless mechanical work has been done on it. Such an experiment, although it does not prove that heat-refining is impossible, yet shows that refining by heat treatment alone will have to be studied further before we can rely upon it, or draw definite conclusions in regard to it. But the real cure for coarse structure is the application of mechanical deformation at a high temperature. Metals are still crystalline at these high temperatures, and when work is applied they undergo deformation by a process of slip; but the deformed crystal has a larger surface and a larger boundary area than had that same crystal before deformation occurred. Therefore it is less stable and more apt to grow and change its shape at a high temperature. During the process of deformation and continuous annealing, which constitutes "hot working," the re-growth of the crystals is taking place the whole time. In passing metal through the rolling mills, however, we are constantly deforming the crystals which are all the time tending to grow, only that the rate of growth diminishes as the temperature falls. If we go on long enough we will go on breaking up this structure down to a temperature at which growth becomes slower and slower, and if we finish our rolling process at a sufficiently low temperature the structure will be very fine. If we have carried the rolling process too far, however, we will have set up serious deformations which the annealing process has not been able to undo, and we will have hard metal in an unreliable condition; but if we finish at the proper temperature the metal will be left in the proper form. That is the rationale of "hot work."

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* Proceedings 1904, Plate 40.

The effect of excessive or prolonged heating upon the micro-structure of steel is illustrated by Figs. 69 and 70, Plate 16. The former represents a steel whose original carbon-content was 0·36 per cent., but which has suffered considerable decarburization in consequence of the prolonged exposure to a high temperature which it received by way of a laboratory experiment. The excessively coarse and angular character of this structure is typical of such overheating, and corresponds to a very serious deterioration of the material from the mechanical point of view. Fig. 70, on the other hand, shows a less violent degree of overheating, but the typical angular character of the structure is still evident. This specimen is taken from a practical case—a motor-car stamping which broke in use.

There is one other pitfall about steels which I wish to illustrate. I have so far spoken of the general effect of heat and the refining effect of the critical temperatures; but there is another effect which may occur, and it is a very undesirable one, from a mechanical point of view. This can be obtained by heating steel at a point which is just below its transformation temperature. In the diagram Fig. 8 (page 252), along the line HIJ, the solid solution in the case of 0·9 per cent. carbon steel, or the residual solid solution in other steel, undergoes transformation into the finely laminated constituent pearlite, which I described in the last Lecture. The finely laminated character of this pearlite is, however, an incident rather than an essential characteristic. Along the line I IJ there is a simultaneous separation of cementite and ferrite crystals, and if that is carried out at a rapid rate, the two constituents separate out in fine lamellæ, having the mechanical virtues of pearlite, but if the metal is held at a temperature just below this line, that is to say about 650° C. (1,202° F.), then this separation of the cementite and ferrite in fine lamellæ is apt to be undone, and instead of forming fine lamellæ, the various crystals of cementite and ferrite run together into comparatively large masses, and we have a structure which consists of ferrite with cementite lying in it as a network, and so far from being a strong structure it is a very weak one. As an example of the consequences which may arise from this kind of treatment, one may take the steel of a boiler-plate which cracked badly between the rivet-holes. This steel shows the structure which results from prolonged exposure to a temperature between 600° and 700° C. (1,112° and 1,292° F.), just below the temperature of pearlite formation. Fig. 71, Plate 17, shows the microstructure of this steel as seen in a specimen etched with sodium picrate, which stains cementite deep black, while leaving pearlite light grey. The photograph shows veins of cementite, and only a few patches of pearlite. The microscopical appearance of the cracks which occurred in this steel is shown in Fig. 72. These cracks are peculiar and do not show the ordinary appearance of a crack in steel, because of their curious polygonal shape. This shape suggests that the cracks follow the boundaries of the ferrite crystals of the steel. Fig. 73 represents the same area, but under a higher magnification, and after etching; it shows that the cracks really follow the boundaries of the crystals in this metal.

Now in sound material the normal course followed by a crack lies across the crystals, along the cleavage or gliding surfaces of the crystals, and not around the boundaries. In normal sound metal the inter-crystal boundaries are considerably stronger mechanically than the body of the crystal, and therefore the fracture does not follow the boundaries. If fracture does follow the boundaries, we may conclude that there is something weak in those boundaries which has come there as the result of abnormal composition or abnormal treatment. It is with this latter that we have to deal here. This condition of the steel is due to the prolonged heating at a temperature below 700° C. which this steel has undergone. In order further to confirm this, we have compared the shock-fracture of this steel with that of normal steel, and here again this abnormal steel shows a fracture following the crystal boundaries. The section seen in Fig. 74 shows how the crystals have broken off bodily instead of the fracture running square across the ferrite crystals as in normal metal. The precise manner in which this abnormal treatment has been given is very difficult to ascertain in workshop practice. It is probable that it might be the effect, for instance, of steel plates which are being heated for ordinary purposes having been left in the furnace for a long time at a dull heat, particularly as one would be apt to think that so moderate a heat would do very little harm. But prolonged heating at a temperature below 700° C. (1,292° F.) results in the formation of free or segregated cementite, and causes a tendency to crack along the boundaries in this abnormal and dangerous way.

I have now to turn to another section of the subject, which I have left until the last, partly because it is difficult, but also in part by reason of its special interest and importance. I refer to the question of the hardening and tempering of steel. The steels to which I have so far referred this evening have been structural steels; that is to say, steels containing less than the eutectoid proportion of carbon, and the properties which I have considered in connection with them have all had relation to excessively prolonged heating, excessively slow cooling, or prolonged heating at special temperatures. On those steels the effect of rapid cooling is comparatively small. It does produce effects which are, in a general way, beneficial, but the effect of rapid cooling is of vital interest in the case of high-carbon steels, that is to say, steels containing from ¾ per cent. to 2 per cent. of carbon. As we all know, the hardening of steel for the production of cutting tools and for other technical purposes is carried out by means of quenching, in other words, by producing very rapid cooling. I am now referring to carbon-steels and not to high-speed tool steels, which must be dealt with separately.

What is it that happens when a carbon-steel is quenched from a very high temperature? The general tendency of such sudden cooling is to preserve the condition of the metal as it existed at the moment when the cooling commenced. If it were possible to bring about cooling with infinite rapidity, so that the metal could be frozen, as it were, in the condition in which it existed when hot, we should then have in the cold metal an exact representation—an exact reproduction of the state which existed in that metal when it was at the high temperature. But in practice this never occurs; the velocity of cooling is never high enough to prevent the occurrence of some of the transformations which are shown on the diagram of Fig. 8 (page 252). Some of those changes occur to a greater or less extent in all practical quenching. The fastest actual cooling time for a small piece of steel is still a matter of some 5 or 6 seconds, and during that short interval, as we can well understand, a great deal can, and actually does, happen in such a complex body as steel. If it were possible to cool steel from a high temperature in, say, one-tenth of a second, I think we should get much simpler results. But that being impossible, we have to consider what is the nature and the condition of the steel at the moment of quenching, and then we have to consider the changes which go on in it in spite of the quenching. If we refer back for a moment to the equilibrium diagram, Fig. 8, we see that in the area A D I G E there is a region in which the metal consists, according to that diagram, of Gamma-iron containing carbide of iron in solid solution. In other words, the steel in that region, if it could be examined at that temperature, should have a simple polyhedral structure, like that of a pure metal or any ordinary solid solution alloy, such as brass, containing, say, 75 per cent. copper when it has been slowly cooled. That is a solid solution alloy in which there is a single constituent forming a crystalline aggregate occupying the whole specimen, and homogeneous throughout. This result is never obtained by quenching carbon-steel, but recently it has been possible to examine the structure of the steel while it is hot; this is not done by placing it under the microscope while it is hot, but it is *etched* while it is hot and examined afterwards. And that, it may be remarked, is a perfectly legitimate process, because the etching simply produces on the surface of steel a surface pattern in relief or intaglio which represents the constitution of the metal at the moment when the pattern was formed. Anything which occurs within the steel after the etching has been completed is practically without effect upon that surface pattern. It is much like imprinting a pattern on a metal by means of a die, or making an impression on a coin, and then annealing that coin afterwards. By the annealing we alter the internal structure of the metal, but not the surface pattern. In the hot-etched specimens we have imprinted a pattern on the metal by the etching reagent, and although the steel undergoes transformations when it is afterwards cooled, the surface pattern stands as the representative of what we would have seen if we had examined it while it was hot. This has recently been done with a series of steels by a Russian worker, Baykoff, working in France under the superintendence of M. Henri Le Chatelier, and his work has been confirmed and is now being extended by Mr. D. Ewen and myself. M. Baykoff has produced a remarkable series of photomicrographs of steels etched at a temperature of 1,120° C. (2,048° F.), and he finds that at such a temperature steel consists of a polyhedral aggregate, exactly as the solid solution theory would lead us to expect.

There is another way of examining this same solid solution, namely, by the addition to the steel of certain alloy elements, such as nickel or manganese in considerable proportions. These have the property of lowering the temperatures at which the changes indicated by the lines of the equilibrium diagram take place. When 10 per cent. of manganese or 25 per cent. of nickel are present, these critical points are depressed below the ordinary temperature, or to a temperature just above the ordinary temperature. In these alloy-steels the region of Gamma-iron solid solution extends to so low a temperature that the Gamma-iron solid solution remains stable in the steels when cold. These steels are very remarkable; they show a microstructure which looks like ferrite—it is a polyhedral structure, and we have a homogeneous metal, consisting of one constituent only. It is a solid solution containing carbon, nickel and manganese, and the metal is non-magnetic, is ductile and tough. Fig. 75, Plate 18, shows the microstructure of one of these Gamma-iron nickel-steels, and this closely resembles, in general outline, the ordinary character of ferrite or any other pure metal or solid solution. This particular example is from a steel containing 10·7 per cent. manganese; the next figure, Fig. 76, is from a steel containing only 2 per cent. manganese and 1·7 per cent. carbon, and it has been rapidly cooled from 1,100° C. (2,012° F.) Thanks to the presence of manganese, the changes which would have occurred in pure carbon-steel have been inhibited, and there is again the same simple polyhedral structure.

Now we pass on to the pure carbon-steel, which Baykoff etched at a temperature of 1,100° C. (2,012° F.). Fig. 77 is from a 2 per cent. carbon-steel etched by gaseous hydrochloric acid. This consists of polyhedral grains. The surfaces are roughened, because the etching cannot be watched under the microscope when it is done on red-hot metal in an atmosphere of hydrogen. But one can see the essential outlines of the polyhedral grains like those we find in Gamma-iron steels. Fig. 78 shows the same material under a higher magnification, clearly showing the crystalline structure of those polyhedra. Fig. 79 represents another steel, containing only 0·12 per cent. carbon; and this also has been etched at a temperature of 1,100° C. Figs. 75 to 79 have been taken from M. Baykoff's Paper; Fig. 80 is a photograph taken at the National Physical Laboratory by Mr. Ewen; this also represents a steel etched by means of gaseous hydrochloric acid—in this case the heating was done in a high vacuum. The magnification is high (× 530) and the photograph shows the characteristic twinning of which I have already spoken in connection with the behaviour of Gamma-iron under strain.

We have here direct evidence that what the equilibrium diagram demands is correct, that the steel at those temperatures is a homogeneous solid solution. When we obtain that solid solution unaltered at the ordinary temperature, either entirely unaltered in the case of nickel-steels or manganese-steels, or partially unaltered as a partial residuum in the case of quenched carbon steels, we give that solid solution a name—austenite. That is the first of the constituents found in hardened carbon-steel. This pure austenite can only be found by examining *carbon*-steels at high temperatures. When we quench carbon-steel, the austenite always undergoes decomposition, and this decomposition is more or less complete. If the quenching is slow, that is to say, if it is ordinary cooling, the austenite decomposes in the way set out in the diagram, into ferrite, pearlite, or cementite and pearlite, or possibly pearlite only (if it happens to be eutectoid steel), but between the condition of homogeneous Gamma-iron or austenite and completely heterogeneous segregated pearlite, we have a series of decomposition products which have puzzled metallographers.

These products have given rise to a great variety of opinions, to exceedingly interesting experiments, and to animated discussion. I do not think there is a single one of those intermediate products which can be defined with the same precision as I have tried to define austenite, ferrite, pearlite, and cementite. Certain of these intermediate transition products show fairly well-defined and definite characters. And upon those characters have been based names of constituents, simply for the sake of convenience. Much discussion has taken place as to the exact nature and character of each of these stages; but if we remember that what is indicated by the names is a particular stage, and that the names do not indicate isolated and definite things, then we see that there is room for a great variety of opinion, because different workers producing these intermediate or transition substances in slightly different ways, will naturally find slightly different results. It is as if one were to discuss the nature of blue light, and one had a continuous spectrum to deal with, but had no means of measuring wave lengths. In that case, unless the colour were right in the middle of the blue region of the spectrum, what one man still called blue might contain a slight amount of violet on one side or of green on the other, and might no longer appear "really blue" to another observer. At the points where one colour is merging into other colours there is room for differences of opinion as to the exact shade. What takes place in regard to the transition products of hardened and tempered steels is somewhat similar. I shall now illustrate, by means of some photographs, the characteristic structures and appearance of one or two of these transition products, and I will try to suggest what may be their nature. I then propose to leave you to read for yourselves the opinions of a number of authors on these matters, and to follow the future development of this subject, because it is evident that it has not yet by any means reached finality.

First of all let us take the transition products which occur when high-carbon steel is quenched very vigorously. This kind of quenching is not one which can be recommended for practical purposes. Some people have rather scoffed at metallographers for working with those excessively vigorous quenchings. But they need only be reminded that this is done not for the purpose of making cutting-tools, but to study the behaviour of these metals under varying conditions.

Before we go on to consider quenching, it is necessary to pay some attention to the decomposition of this austenite in another way. Austenite, after all, if it is maintained in existence, or partially so maintained, by quenching, is a supersaturated solution. A supersaturated solution, as is known, is a very sensitive substance. If one takes crystals of ordinary "hypo" as used by photographers, and adds a little water to them, and warms the mixture, the whole mass will melt, and then it can be cooled to the ordinary temperature. If this substance is left alone, it still remains liquid. But if it is shaken a little at that temperature, and still more if a tiny fragment of "hypo" crystal is dropped into it, the whole mass solidifies instantly; the over-burdened solution rapidly deposits its burden on the slightest provocation. And that is what austenite is very apt to do during the process of the quenching of the metal, and also in other ways.

The Gamma-iron nickel-steels, of which mention was made a little earlier, are very near the boundary where the austenite of which they consist is stable at the ordinary temperature. In fact, sometimes it is not stable, but is in a condition of under-cooled solution, which tends to deposit its burden of crystals on the slightest provocation. Fig. 31, Plate 8, shows such a nickel-steel which has been polished and strained, and upon which has been developed a beautiful system of slip-bands. These have already been mentioned in another connection in the first Lecture. This specimen has been used for an interesting experiment. This nickel-steel has the peculiar property that although it is soft and ductile in the ordinary way and under ordinary circumstances, yet when strain is put upon it in any way, or when one tries to cut it with a cutting tool, it hardens up, and becomes quite a hard metal. That is due to the fact that the austenite of which it consists, in this soft condition, has undergone transformation into a hard condition. And the question arose in my mind as to whereabouts in the metal this happens. Is the transformed, hard material uniformly distributed everywhere, or does it occur only at those points where this solid solution has been scratched or disturbed by the process of slip? In fact, is the hard constituent, which has been formed as the result of the strain which has been put upon the steel, confined to the slip surfaces? The experiment by which I tested the matter consisted in preparing a specimen like that shown in the photograph, and watching it under the microscope while putting upon it an etching reagent whose action would reveal the presence of the changed constituent. Fig. 81, Plate 18, shows the result; along all the former lines of slip there is an appearance of the changed constituent. If the specimen had been ferrite, or copper, or any other ordinary metal, by applying an etching reagent to surfaces strained in that way, the whole of the slip-bands would disappear; it would etch uniformly, and nothing of the kind seen in Fig. 81 would appear.

The effect is very definite. The fact that the dark-etching constituent appears along the slip-bands proves that the metal has undergone transformation, and that the transformation has taken place on the very planes where slip has occurred—where the supersaturated solution has been disturbed. That being so, we may look for the transformation products which occur during quenching to have the same distribution, because during quenching we are subjecting that solid solution to very severe mechanical treatment. The outer shell of the metal is cooled suddenly, before the inner shell has been able to cool. Consequently the outer shell contracts upon the inner core and produces a serious stress, as those whose business it is to deal with the hardening of gauges and dies know too well, and this is accompanied by a serious distortion of the shape of the mass. That distortion can only be accomplished by slip going on in the crystals of austenite, and it is on the planes where that slip has occurred that we find these decomposition products. This is illustrated in Fig. 82, Plate 19. This is similar in general character to the strained and etched nickel-steel, but this is hardened steel, containing 2 per cent. of carbon, quenched from a temperature of 1,000° C. The dark-etching decomposition product has been formed on the cleavage planes of the austenite, and it assumes a very characteristic appearance. Fig. 83 is an example of how this transformation product follows the twinning of the austenite.

The next figure, Fig. 84, takes us a step further. This represents a steel which contains nearly 2 per cent. of carbon; and a great deal of heat and time is needed to enable the Gamma-iron to dissolve as much carbon as 2 per cent. The consequence is this, that probably at the moment of quenching in the Gamma-iron crystals, although there was probably no actual free cementite, there was something, probably very minute traces or nuclei of cementite, and during the rapid cooling these nuclei acted as centres for the deposition of the transition product. As a consequence, therefore, we find thick masses of this transition product following all the boundaries of the original crystals. But in addition to that, in the mass itself, the austenite has undergone decomposition; it is no longer a uniform structure, but it has a light and a dark-etching constituent. This dark-etching constituent, which, under higher magnification, shows a peculiar structure of its own, has received the name " martensite." This is merely a name for one particular stage of this decomposition process, and this stage has a peculiar and fairly well-defined structure of its own. It is the hardest stage in which the steel exists. There is no doubt that the dark bands of martensite are harder than are the light areas. The formation of this martensite is probably what happened in the case of the nickel-steel illustrated in Figs. 31 and 81, Plates 8 and 18, where the decomposition had been brought about by strain, and decomposition products had been formed. Here we see places where decomposition has taken place to a certain extent, and there the metal is intensely hard. Fig. 85, Plate 20, shows another example of the same kind, the martensite and austenite structure showing the peculiar forked lightning effect which is typical of austenite and martensite in severely quenched high-carbon steel.

Fig. 86 shows the structure of martensite alone when it is highly magnified. If we take a steel containing say 1 per cent. of carbon, and quench it from a temperature which is not excessively high, the whole of it will be seen to consist of this structure. The metal will be exceedingly hard, and that is the typical appearance of this constituent known as martensite. It has sometimes been suggested that the structure shown in Fig. 86 is a sign of excessive hardening, and that it should not be met with in a steel which has been "properly" hardened. I cannot agree with that view, because I find in practice that most steels when fully hardened but not tempered, when "properly" hardened, that is to say hardened at the lowest temperature at which complete hardening can be obtained, show this definite martensitic structure.

What is the nature of the process of transformation which austenite has undergone in passing to martensite? This has not yet been finally proved, but I am inclined to adopt the view that the iron has changed from the Gamma to the Beta condition, and that this change has involved some rearrangement of the carbon. In the slow cooling of steel from a high temperature we start with the iron in the Gamma condition and the carbon completely dissolved, and after slow cooling we have the iron in the Alpha condition, and the carbon completely thrown out of solution and separated as cementite. We have thus a change of the iron from the Gamma to the Alpha, and the complete separation of the carbide, and those two changes go on more or less side by side in these transition products. The first step, I believe, is the transition from Gamma on towards Alpha iron. But I do not think that transition takes place in only one step; it is probable that the hardness of the hardened steel is due to the fact, or at least partly due to the fact, that in this martensite the iron itself is present in the Beta condition, which, as I showed in the last Lecture, is known to be hard, though not of the "adamantine" hardness which has been claimed for it. Still, it is harder than Alpha-iron. The reason for supposing that we have Beta-iron in this condition is, that we know *pure* iron cannot pass from the Gamma to the Alpha condition without first passing through the Beta condition. It is true that when there is more than about 0·4 per cent. of carbon present in the steel, there is no temperature at which iron will remain permanently in the Beta condition, but that it will none the less pass, transitorily, through the Beta condition is quite probable. If it is a question of the number of atoms in the molecule, one knows that the Beta condition is intermediate between the Alpha and the Gamma condition, and it is only natural, when the change takes place at any time, even in the presence of carbon, that this intermediate condition should occur for a time. There are similar facts in ordinary chemical reactions. For instance, if carbon and oxygen are allowed to unite completely, carbon dioxide is formed if the gases are present in the right proportions, but if the action is interrupted a certain proportion of carbon monoxide will be found present temporarily. And similarly it may be supposed that Gamma-iron in the presence of a considerable proportion of carbon has first of all passed temporarily into Beta-iron, and in that condition helps to confer this extreme hardness.

Meanwhile the carbon has had to move. It could not remain where it was, because the Beta-iron has very much less power of dissolving carbon, and that carbon has had to be rejected by the iron. In the case of martensite, that rejection has not gone very far. But when we come to the next stage and make the cooling slower, we find a stage in which the carbide of iron has been rejected from solution, but has not been allowed to gather together into nodules or lumps. Instead, it is present in a state of very fine division, which Benedicks calls, as I think quite rightly, colloidal suspension. When a steel containing this colloidal suspension of carbon in one of the allotropic forms of iron is etched, the etching reagent deposits a dense black film on the metal, and there is a very rapid etching of the structure. Fig. 87, Plate 20, shows an example of this condition. It represents a steel which consists partly of martensite, but the structure of the martensite, owing to the exigencies of the photograph, is not shown very well; but we see that there is another constituent showing a different colour, and that is because the rejection of the carbon out of the solid solution has gone a step further. This stage has received the name of troostite. It represents the second step in the degradation of austenite towards pearlite. The iron present in it is probably still in the Beta condition; but the carbon, or rather the iron carbide, has been rejected from solution, and is in suspension.

If this process is allowed to go further, the carbide begins to coagulate into masses, and thus commences to form particles of cementite. At first these are very fine, so fine that one cannot distinguish them, and they cannot be resolved under the microscope. This condition is called sorbite. If the growth of particles of cementite goes a little further, we have pearlite. Fig. 88 shows the whole of these constituents together. This photograph has been obtained by quenching a carbon-steel of nearly eutectoid composition at the moment when it was undergoing transformation. We watched it cooling down until it began to show the evolution of heat at 700° C. (1,292° F.), and at that instant the water was admitted into the apparatus. This specimen has been quenched by washing it out of the furnace with a current of water, so that it was caught in the act of transition. All of it is not in perfect focus, but one can recognize the curious needle-like structure of martensite and the dark troostite verging into sorbite and into well-developed pearlite in the middle. These then are the transition stages found in hardened steel, and we may think of them as resembling the transitions of colours in a continuous spectrum; they merge more or less imperceptibly into one another, but although there are certain well-defined stages, yet there are no hard and fast boundaries.

What is the cause of the hardness of quenched steel? The answer which I am inclined to give to that question is that there is not one cause, but a number of causes acting together. There is, in the first place, good reason for believing that the hardness is due in part to the inherent hardness of the iron forcibly retained in the allotropic condition, possibly the Beta condition. But there is also another fact; the austenite of carbon-steels is a solid solution which on slow cooling would clearly deposit its burden of dissolved cementite. But this is prevented by rapid cooling or forcible mechanical pressure; and such forcible retention of a solution as a solution nearly always involves internal molecular stress, which certainly implies mechanical hardness. A striking example of hardness of that kind, quite apart from any action of quenching in the ordinary sense, is the process seen in the manufacture of ordinary glass. Glass at a high temperature, as we all know, is a liquid solution of a number of silicates in one another. If allowed to cool slowly, occupying many weeks, such glass can be converted into a crystalline aggregate; those crystals are very much like the crystals of felspar, and they are comparatively soft. But if cooled at the ordinary rate the condition of mutual solution is maintained down to the ordinary temperature, and we have a glass which, as we ordinarily know it, is an intensely hard body. The difference in hardness between the under-cooled liquid solution in this case and the devitrified glass of the felspar silicates is due entirely to the molecular disturbance and stresses, the constraint arising from the forcible retention of the substance in the condition of solution at a temperature where it would not normally be in solution. The corresponding phenomenon is found not only in steel, but also in certain alloys, such as those of copper and aluminium. About a year ago I gave an example of this, in this room, by sharpening a cedar pencil with an aluminium-bronze implement, which owed its hardness to this same cause.

Those, then, in my opinion, are two causes. A third cause—because these may not be the only ones—may lie in the mechanical pressure which is put upon quenched steel by the rapid contraction of the outer shell. In the case of fairly large pieces of steel, that pressure must be considerable. But it is possible to harden steel in the thinness of wire, and then these stresses cannot amount to much, and therefore this cause cannot be considered as vital. The essential ones I regard as these two: the retention of the iron in the allotropic condition, and the forcible retention of the carbon in solution.

I now want to warn you—although for the sake of simplicity and clearness in presenting the subject I would have liked to omit it—that the views which I have put before you as to the hardening of steel and the nature of the constituents are not quite universally accepted; the views which I have put forward in somewhat general terms would, I think, be accepted by the great majority of metallurgists both in this country and abroad. I may say I have put these views before you in broad terms so as not to raise controversial points of detail, and I have especially tried to avoid dogmatizing on points which are not absolutely certain. But in this country there are some few metallurgists who hold a different view, and I wish to devote a few minutes to a consideration of their views. Those views have not yet been expressed in the form of an equilibrium diagram, such as that shown in Fig. 8 (page 252), and that perhaps is the severest criticism which one can make. Because if a view is logical and complete, I submit that it is one which must be capable of being expressed in a diagram consonant with that view and with the known laws of heterogeneous equilibria. That, as I say, has not been attempted yet by those who decline to accept the allotropic theory in the form in which I have put it before you.

They say that the hardening is due entirely to the presence of the carbon in the steel, and that its presence makes itself felt by the formation of a definite compound $Fe_{24}C$, and that this formula represents the composition of the eutectoid steel, lying at the point I on the diagram of Fig. 8 (page 252). And the suggestion is that at temperatures above 700° C. we have not a solid solution of carbide of iron in Gamma-iron at all, but this chemical compound or sub-carbide, and that when this compound cools to the temperature of transformation we have, not the decomposition of the solid solution but the decomposition of the sub-carbide resulting in the deposition of duplex pearlite. When we quench the steel we retain this "hardenite" as a compound, and prevent its decomposition. So that this substance is supposed to be the source of the hardness of quenched steels.

On the face of it this might be so. I can indeed show what appears to be an argument in support of that view, namely, an analogous case where the decomposition of a definite compound gives rise to a duplex constituent which looks very like pearlite. In the course of a research on the alloys of aluminium and zinc carried out in connection with the Alloys Research Committee of this Institution, my colleague, Mr. Archbutt and I, found that a definite compound of aluminium and zinc—$Al_2 Zn_3$—at a certain temperature undergoes decomposition into a duplex structure very similar to that of pearlite: an example of this structure in an alloy of aluminium and zinc is shown in Fig. 89, Plate 20. This condition is the result of very slow cooling—quenching from a temperature above 256° C. (493° F.) renders this alloy homogeneous. This analogy seems to support the "sub-carbide" theory. But that is as far as we can go, because the question arises, how is such a compound formed in iron-carbon alloys at all? In the aluminium-zinc alloys, the formation of the compound Al_2Zn_3 can be fully accounted for. Now our study of alloys has led us to know fairly well what must be the shape of a freezing-point curve if a definite compound is formed in the series. We, therefore, know that if a compound $Fe_{24}C$ were formed from fusion, there would have to be some discontinuity, some irregularity at that point of the liquidus curve of the diagram, Fig. 8, lying near the concentration of the compound (about 0·9 per cent. carbon). But the work of five or six independent investigators absolutely disproves the existence of any "kink" or break in the liquidus of these alloys near that concentration. Therefore this sub-carbide, if it exists at all, is not formed by crystallizing from fusion. Is it formed at a temperature below the solidus? It might conceivably be formed, like the aluminium-zinc compound, by a reaction taking place in the solid metal, but in that case we should find in that region of the diagram a series of heat evolutions, having a definite maximum of intensity at the concentration of the compound. Our experiments show that there are no such heat evolutions at all, and therefore I feel convinced that no such compound is formed in the cooling of steel; that in eutectoid steel above Ar_3, we have not a compound, but a solid solution, and that the diagram which I have described in Fig. 8 is substantially correct.

I have detained you so long already that I cannot stop now to summarize what I have said or to emphasize further some of the more important points, but I think I have said enough to show what an interesting tale the microstructure of a given steel can be made to tell. Chemical analysis can tell us the average composition of the steel, but the microstructure enables us to judge of the distribution of the various constituents. Further, I have endeavoured to show how the microstructure is dependent not only on the chemical composition of the steel but also upon the thermal and mechanical treatment which it has undergone. When those relationships are properly understood, it is possible to form from an examination of the microstructure a very good idea of the past history of a piece of steel—the kind of heat and mechanical treatment which it has received and whether it is in a satisfactory or in an unsatisfactory condition. Accordingly, it may well be claimed that the metallographic researches, which have been carried out by so many investigators, have not only thrown a flood of new light on the whole subject of the nature, constitution and behaviour of metals, but they have also placed in our hands a powerful new method of testing and investigation. We may well hope that the further progress of such research will clear up many of the mysteries which still enshroud the behaviour of our metallic materials of construction.

The Lectures are illustrated by Plates 5 to 20 and 15 Figs. in the letterpress.

Permission has been kindly granted to reproduce the following Figs:—

From the Board of Trade Report upon "Defective Plates in the Combustion Chambers of a Foreign-going Passenger Steamship." Figs. 71, 72, 73, and 74.

From the Journal of the Iron and Steel Institute. Figs. 23, 27, 28, 31, 40, 56, 57, 58, 59, 60, and 81.

From "Metallurgie," Zeitschrift für die gesamte Hüttenkunde. [Journal for the Science of Smelting.] Edited by W. Borchers and F. Wüst, Published by Wilhelm Knapp, Halle-on-Salle. Figs. 10, 11, 12, 13, 14, 15, 16, 75, 76, 77, 78, and 79.

From Proceedings and Philosophical Transactions of the Royal Society. Figs. 32, 33, 34, 35, 36, 61, 62, 63, and 64.

From the Proceedings of the Staffordshire Iron and Steel Institute. Figs. 24, 25, and 66.

The Chairman (Professor Gowland) said he thought that all would agree with him when he said that they had listened with the greatest interest and pleasure to the extremely instructive Lectures which they had heard from Dr. Rosenhain, in which he had so ably and clearly set forth the very difficult subject, or at least the difficult points in the subject, of the theory and practice of metallography as far as steels were concerned. There were one or two points in the last Lecture—and he would confine himself to one or two—about which he would like to say a few words. The Lectures threw a flood of light upon the treatment of steel by heat and by mechanical methods. In the next place, he was very pleased to find that the proposal—which had now been carried out—of refining steel by heating up to a certain temperature, must be put into practice with considerable care. In fact, from what

Dr. Rosenhain had told them, all that had been put forth as a result of this refining process could not be accepted. The all-important effects of heat treatment Dr. Rosenhain had put before them most clearly, and in fact they could not but admire the very lucid manner in which this difficult subject has been presented.

As regards austenite, he was very pleased to hear Dr. Rosenhain's definition of that, and of its composition under various conditions, more particularly as it bore the name of his distinguished predecessor at the Royal School of Mines. With regard to those other—he supposed he must not call them constituents, but condition-forms—sorbite, troostite, and martensite, he was extremely pleased to find that Dr. Rosenhain held that these were merely transitions, and that they must not be considered as really constituents of the metal.

Now, he would go back for a moment to pre-metallographic days—days not of very long ago—when chemical analysis was relied upon chiefly for throwing light upon the abnormal behaviour of metals, more particularly with regard to unexpected fracture, excessive corrosion, and similar effects. These results, as was well known, especially by the older members of the Institution, were too often unsatisfactory and inconclusive. And for this reason: because when one pursued an investigation into the failure of a metal on the lines of chemical investigation or analysis, one very often found that metals having exactly the same chemical composition, and the alloys also, behaved entirely differently under mechanical treatment and in work; because we did not then know the effect which the heat treatment had, not only on steel, but also upon various alloys, copper, and the like. Therefore, chemical composition did not tell them all that they wanted to know about the metal. Of course it was necessary, in order that we might know and determine the amount of injurious impurity which metals or alloys might contain; but that was all it could do. And hence it was necessary, in the examination of metals in the present day, to remember that the chemical analysis must not be relied upon alone, but that we must subject the metal to careful microscopical examination, and have properly prepared sections.

(Professor William Gowland.)

With regard to the metallography of steel, it was extremely interesting and important that we had had these two Lectures—the first, he hoped, of a series—on that subject. But it must also be borne in mind that the metallography of the non-ferrous metals was also of very great importance, and he hoped the Institution might see its way to supplement those Lectures which had been given by Dr. Rosenhain, by others which would deal with the non-ferrous metals, more particularly copper and copper alloys, which were of no small importance to mechanical engineers. And it had been, and was, a source of great satisfaction, he thought, to all the members of this Institution that the Council had seen its way to institute these Lectures. He need hardly say that a more able exponent of the Metallography of Steel could not be found than in Dr. Rosenhain. Finally, he was sure it would be the wish of the meeting to accord Dr. Rosenhain their heartiest thanks for the extremely instructive and able Lectures with which he had favoured them on these two occasions.

Dr. H. S. HELE-SHAW, Member of Council, said that the members of this Institution were very much gratified that Professor Gowland had spoken in the way he had of the Lectures which had been delivered by Dr. Rosenhain. Professor Gowland was one of the great authorities on this subject, and they were very grateful to him for adding those valuable remarks from the Chair, and he assured him that they would most carefully consider what he had said. It was perhaps fitting that he should say that the members themselves considered that Dr. Rosenhain had exactly "filled the bill," and that he had given them exactly what they asked him for, and what they wished to have in these Lectures. Sometimes we appreciated a lecture but did not realize that there might be twenty ways and more of treating the subject. Of those ways many might be utterly unintelligible, although the lecturer might be well conversant with his subject, and the rest might be quite dull and uninteresting. They all felt that, on this night and on the last occasion, the right way of treating the subject had been taken, and they were very grateful to Dr. Rosenhain, because they knew that such a result had not been arrived at without a combination of accurate knowledge and experience derived from personal research. Dr. Rosenhain had made them appreciate, perhaps for the first time, the great importance of photomicrography, and the real bearing it had in studying the behaviour of steel. He must say, for his own part, that he never understood the action of heat on metals so clearly as when he saw the photographs that night, and realized that what was wanted in addition to heating a metal, was plenty of mechanical work, in order to produce a sound material. He expressed the hope, in the name of the Institution, that this would not be the last time they would hear Dr. Rosenhain, and he had the greatest pleasure in seconding the vote of thanks.

The vote was carried by acclamation.

Dr. Rosenhain thanked Professor Gowland, Dr. Hele-Shaw, and the meeting very warmly indeed for the kind manner in which they had appreciated his efforts in these Lectures. As he said when he began them, it was a formidable task to undertake them, but the real cause of gratitude which the meeting ought to express was not what he said, but what he did not say. There were so many other things in his notes on which he did not touch, that he had saved, he thought, at least another hour altogether by leaving them out. Nobody could thank him for that, because they did not know. But, seriously, he felt that the Council of this Institution had done him a very great honour in asking him to give these Lectures, and if he had been able, to even a small extent, to fulfil their wishes, and to give some little insight into the meaning and possible value of all this work on the microstructure and constitution of metals and alloys which was being done now, he was more than repaid for the small amount of trouble which had been taken. He thanked them for their patience in listening to him, and for their great kindness in passing the vote of thanks.

Mr. Mark Robinson, Member of Council, said that one thing remained yet to be done. They had had lustre shed on their proceedings by the Lectures to which they had listened, and they

(Mr. Mark Robinson.)

had expressed their gratitude to Dr. Rosenhain for them. Let them now express their gratitude to Professor Gowland, who had added further lustre to their proceedings by presiding over them that evening. He thought they would all thank him very heartily.

Carried by acclamation.

Professor **Gowland** replied that he felt it a great honour indeed to be asked to preside at that Lecture, and it had also been a very great pleasure, because he had known Dr. Rosenhain a great many years, and he was an old friend of his. He first made his acquaintance under rather peculiar circumstances. It was not at a meeting of the Iron and Steel Institute, nor at a meeting of the Institution of Mechanical Engineers, but it was at the Anthropological Institute, where Dr. Rosenhain had made an examination of a weapon, and by his examination, for the first time, showed us how that a Malay kriss had been built up by a mixture of hard and soft steel and iron. He thanked them very much for the vote which had just been accorded to him.

The Institution of Mechanical Engineers.

PROCEEDINGS.

April 1911.

An Ordinary General Meeting was held at the Institution on Friday, 28th April 1911, at Eight o'clock p.m.; Edward B. Ellington, Esq., President, in the Chair.

The Minutes of the previous Meeting were read and confirmed.

The President announced that the Ballot Lists for the election of New Members had been opened by a committee appointed by the Council, and that the following fifty-eight candidates were found to be duly elected:—

MEMBERS.

Crawshaw, William Edwin,	Lucknow.
Crouch, John Peachey,	Rosario de Sta. Fé.
James, Alfred,	Chittagong, India.
Jones, Albert Edward,	Fiume, Hungary.
Mitchell, Alfred Hillyard,	London.

ASSOCIATE MEMBERS.

Allingham, Henry William,	London.
Barnes, Thomas Edward,	London.
Baynes, Frederick Walter,	East London, C.C.
Brown, Robert Mackie,	Glasgow.
Budge, John,	Coventry.

Campbell, Albert John,	Hebburn.
Campbell, James Williamson,	Glasgow.
Chapman, D'Arcy Mitchel,	London.
Clunas, James Wilson Stuart,	Cape Town.
Craik, David Craik,	Howrah.
Drury, Reginald Starr,	Hull.
Feeny, Cyril Joseph,	London.
Forbes, George Robertson,	London.
Haffenden, Arthur George,	Birmingham.
Marchant, Herbert George,	London.
Michell, Walter Jabez, Eng. Lieut., R.N.,	H.M.S. "Fox."
Paterson, David,	Cachar, India.
Paterson, John James Crosbie,	Bombay.
Rogers, Lincoln Coslett,	Randfontein.
Sanders, Philip Malcolm,	London.
Sharp, Francis Samuel,	London.
Sington, Leonard Francis Symons,	Liverpool.
Smith, William Garner,	London.
Spear, Charles Oscar,	Camborne.
Stockton, Edward Grimmitt,	Burton-on-Trent.
Tranter, William James,	Tipton.
Turner, Joe Dare Knobbs,	Manchester.
Waddington, Arthur,	York.
Williams, Alfred Edward,	Bombay.
Winter, William,	London.

GRADUATES.

Abraham, Frederick Hermann,	Bradford.
Archbutt, Reginald Charles,	Derby.
Armstrong, Alfred Charles,	London.
Balsom, Ernest Victor,	London.
Banks, Herbert William,	Gainsborough.
Beaton, Harris John,	Derby.
Belton, Charles Moritz Dunsford,	Shrewsbury.
Blanchard, Leslie William,	Peterborough.
Burge, James Frank,	Fleetwood.

Butler, John Lawrence,	Leeds.
Crosweller, Walter William,	London.
Fawcett, Edward George Duncan,	Crewe.
Fearnehough, Harold,	London.
Hampson, Joseph,	Manchester.
Hebblethwaite, William Murray,	Leeds.
Isard, Arthur Percival,	Tonbridge.
Jones, John Maxwell,	Plymouth.
Lloyd, Thomas Butler,	Shrewsbury.
Mackay, Alexander Reay,	Bedford.
Parrack, Leonard,	London.
Ross, Percy James Paviour,	Manchester.
Saad-el-Dine, Aly Fouad,	Liverpool.
Tuker, William Edred Sanger,	London.

The President announced that the following four Transferences had been made by the Council:—

Associate Members to Members.

Brown, Edward George,	Birmingham.
Clapham, Frederick Thomas,	Exeter.
Cumming, William Milligan,	Yokohama.
Pinsent, Sidney Hume,	Buenos Aires.

The following Papers were read and jointly discussed :—

"Gas-Producers"; by Mr. J. Emerson Dowson, *Member*, of London.

"The Effect of varying proportions of Air and Steam on a Gas-Producer"; by Mr. E. A. Allcut, M.Sc., *Graduate*, of Birmingham.

The Meeting terminated at Ten o'clock. The attendance was 114 Members and 66 Visitors.

ANNIVERSARY DINNER.

The ANNIVERSARY DINNER of the Institution was held at the Hotel Cecil, Strand, London, on Thursday evening, 27th April 1911. The President occupied the chair; and the following were among the Guests who accepted the invitations sent to them, although those to whose name an asterisk (*) is prefixed were unavoidably prevented at the last from being present:—

Dr. Thomas J. Macnamara, M.P., Parliamentary Secretary of the Admiralty; Mr. F. Dyke Acland, M.P., Financial Secretary of the War Office; *The Right Hon. Lord Pirrie, K.P., P.C.; Surgeon-General Sir Alfred Keogh, K.C.B., Rector of the Imperial College of Science and Technology; Lt.-Colonel Sir James R. Dunlop Smith, K.C.S.I., C.I.E., Political A.D.C. to the Secretary of State for India; *Mr. Edward White, Chairman of the London County Council; Mr. E. B. Barnard, Chairman of the Metropolitan Water Board; Rear-Admiral A. G. H. W. Moore, C.V.O., R.N., Director of Naval Ordnance and Torpedoes; Brigadier-General S. B. von Donop, Director of Artillery; Colonel H. C. L. Holden, Superintendent of the Royal Gun and Carriage Factories; Captain B. H. Chevallier, R.N., Superintendent of Ordnance Stores, Admiralty; Sir Frank T. Marzials, C.B.; Lt.-Colonel H. A. Yorke, C.B., R.E., Chief Inspector of Railways, Board of Trade; Councillor E. L. Somers Cocks, Mayor of the City of Westminster; Captain H. Acton Blake, Deputy Master of the Trinity House; *Sir James C. Inglis, General Manager of the Great Western Railway; Sir Charles Owens, General Manager of the London and South Western Railway; Sir Ernest F. G. Hatch, Bart., Master of the Ironmongers' Company; Sir Henry Tanner, I.S.O., Architect, H.M. Office of Works; Canon H. Hensley Henson, Rector of St. Margaret's, Westminster; Mr. F. G. Ogilvie, C.B., Secretary of the Science Museum; Mr. F. W. Black, C.B., Director of Naval Contracts; *Dr. R. T. Glazebrook, C.B., F.R.S., Director of the National Physical Laboratory; Mr. Sanford Evans, Mayor of Winnipeg.

Agents-General for the Colonies: The Hon. Sir William Hall-Jones, K.C.M.G. (High Commissioner, New Zealand); The Hon. Sir N. J. Moore, K.C.M.G. (Western Australia); *The Hon. Sir J. W. Taverner (Victoria); *The Hon. T. A. Coghlan, I.S.O. (New South Wales); The Hon. A. A. Kirkpatrick (South Australia); The Hon. John McCall, M.D. (Tasmania).

Presidents of Technical Institutions: The Most Hon. the Marquess of Bristol, M.V.O. (Institution of Naval Architects); Sir Archibald Geikie, K.C.B., LL.D., F.R.S. (Royal Society); The Rev. Professor T. G. Bonney, F.R.S. (British Association); Mr. Alexander Siemens (The Institution of Civil Engineers); Mr. F. W. Dyson, F.R.S., Astronomer Royal (Royal Astronomical Society); Mr. S. Z. de Ferranti (Institution of Electrical Engineers); *Mr. Leslie R. Vigers (Surveyors' Institution); Mr. Michael Longridge (Manchester Association of Engineers); *Colonel R. Saxton White, V.D. (North-East Coast Institution of Engineers and Shipbuilders); Dr. Archibald Barr (Institution of Engineers and Shipbuilders in Scotland); Mr. George M. Ross (Institution of Civil Engineers of Ireland); *Mr. I. Treharne Rees (South Wales Institute of Engineers); Mr. Oliver Imray (Chartered Institute of Patent Agents); Mr. Edward Allen (Liverpool Engineering Society); Mr. Walter F. Reid (Society of Chemical Industry); *Mr. H. Livingstone Sulman (Institution of Mining and Metallurgy).

Dr. J. H. T. Tudsbery, Secretary, Institution of Civil Engineers; Mr. R. W. Dana, Secretary, Institution of Naval Architects; Mr. G. C. Lloyd, Secretary, Iron and Steel Institute; Mr. Leslie S. Robertson, Secretary, Engineering Standards Committee; Mr. A. B. Symons, Chairman, Graduates' Association; Mr. F. R. C. Rouse, Hon. Secretary, Graduates' Association.

Professor J. O. Arnold, D.Met.; Mr. J. Field Beale; Mr. James S. Beale; Mr. Walter Dixon; Mr. J. Emerson Dowson; Captain E. L. Ellington, R.A.; Dr. T. Gregory Foster, Provost, University College; *Professor William Gowland, F.R.S.; Mr. F. W. Harbord; Mr. Cyril Hitchcock; Professor A. K. Huntington; Mr. L. A. Legros; Dr. John Lynes; Mr. R. A. McLean, F.C.A., Institution Auditor; Mr. James Miller; Captain H. L. Nevill, D.S.O., R.F.A.; Dr. Walter Rosenhain; Mr. Basil Slade; Mr. W. T. Western, Chairman, London Hydraulic Power Co.

The President was supported by the following Members of the Council:—*Past-Presidents:* Mr. John A. F. Aspinall; Mr. William H. Maw, LL.D.; Sir William H. White, K.C.B., LL.D., F.R.S.; and Mr. J. Hartley Wicksteed. *Vice-Presidents:* Mr. H. F. Donaldson, C.B.; Mr. Michael Longridge; and *Mr. A. T. Tannett-Walker. *Members of Council:* Mr. William H. Allen; Dr. Archibald Barr; *Mr. Dugald Clerk; Dr. H. S. Hele-Shaw, F.R.S.; Mr. George Hughes; Mr. Henry Lea; Mr. Robert Matthews; Mr. William H. Patchell; Mr. Thomas P. Reay; Mr. Mark H. Robinson; Captain H. Riall Sankey, R.E., ret.; and *Professor W. Cawthorne Unwin, LL.D., F.R.S.

After The President had proposed the loyal toasts, Sir William H. White, K.C.B., LL.D., F.R.S., Past-President, proposed that of "The Empire," which was acknowledged by Dr. T. J. Macnamara, M.P., Parliamentary Secretary to the Admiralty, and The Hon. Sir William Hall-Jones, K.C.M.G., High Commissioner for the Dominion of New Zealand.

The toast of "Our Guests" was proposed by Mr. John A. F. Aspinall, Past-President, and acknowledged by The Rev. Professor T. G. Bonney, F.R.S., President of the British Association, and Surgeon-General Sir Alfred Keogh, K.C.B., LL.D., F.R.S., Rector of the Imperial College of Science and Technology.

The concluding toast of "The Institution of Mechanical Engineers" was proposed by The Worshipful the Mayor of the City of Westminster, Councillor E. L. Somers Cocks, and acknowledged by the President.

GAS-PRODUCERS.

BY MR. J. EMERSON DOWSON, *Member*, OF LONDON.

When the author was asked to write a Paper on Gas-Producers he realized that he would have to confine himself to the consideration of their construction and working, as it would not be possible in a Paper of reasonable length to include the application of the gas to the numerous purposes for which it is used. Originally producer-gas was made exclusively for heating furnaces, but now it is also adopted extensively for gas-engines, and for smaller kinds of heating work in industrial processes, as well as for cooking, baking, and other domestic uses. This has led to the use of *suction-gas* as well as *pressure-gas*, and for engines and many other kinds of work the gas has to be scrubbed and cleaned in various ways, whereas for ordinary furnace work this is not necessary or desirable. There are now many makers of gas plants, but most of them have merely introduced modifications in detail which do not affect the principles involved, and the author proposes to confine himself to certain *types* of gas-producers, and to discuss their leading features from the theoretical and practical points of view. Those who wish to trace the growth of the subject historically will do well to read the Paper * of Mr. F. J. Rowan on "Gas-Producers," and the useful book of M. Jules Deschamps on "Les Gazogènes" (1902).

Before considering distinctive types of producers, it will be well to review briefly the principles and conditions on which the production of producer-gas depends, and it will be seen that, subject to minor variations, the chemical reactions are and must be the same in kind, for pressure- or for suction-gas. A gas-producer may be defined as an apparatus for converting solid fuel into combustible gas; and the gas produced is usually a mixture in varying proportions of carbon monoxide, hydrogen, gaseous hydrocarbons (chiefly methane or marsh gas), carbon dioxide, and nitrogen. The first three of these constituents are combustible, and the value of the gas as a fuel depends on the proportions in which they are present; the carbon dioxide and nitrogen are diluent gases which lower the flame temperature of the combustible gases when they are burnt.

Producer-gas may be obtained from almost any carbonaceous fuel, and the particular kind of fuel to be made use of depends chiefly on the purpose for which the gas is to be used, and on its cost and the ease with which it can be procured in different localities. In practice the gas used for furnace work is generally made from bituminous coal, and for engines and small heating work it is made from bituminous or semi-bituminous coal, or from anthracite or coke; but in some cases brown coal, lignite, peat, charcoal, etc., are used. The composition of the gas is largely influenced by the nature of the fuel, but a further important consideration is that for nearly all purposes (except furnace work) the gas must be free from tar and other condensable products. When hot gas is taken direct from a producer to a furnace any tarry vapours which accompany the gas can be burnt with it, and they add usefully to the flame temperature; but for engines and small heating work where valves, cocks, etc., are required, and where the gas must be cool before it is used, the tarry vapours must be got rid of in the producer or by means of tar extractors and other apparatus outside the producer.

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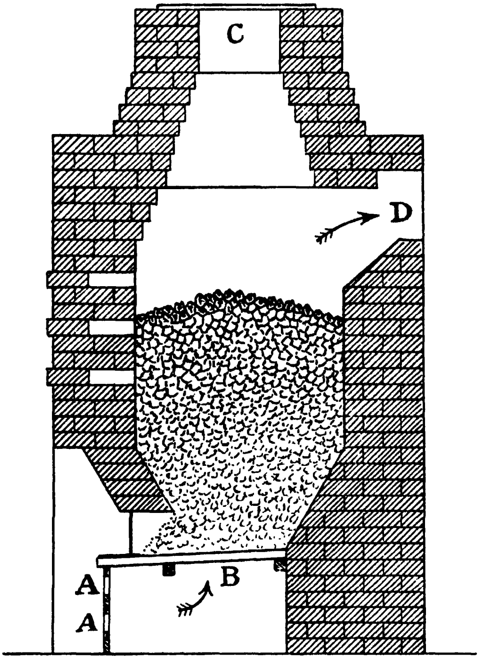
* Proceedings, Inst. C.E., 1886, Vol. lxxxiv, page 2.

Speaking generally, producer-gas is made by forcing or drawing air (with or without the addition of steam or water vapour) through a deep bed of fuel in a closed producer; the solid fuel is converted into gas, and the latter passes away to wherever it is required. An important characteristic of the process is that no external heat is applied to the producer, as in the case of an ordinary gas-retort; when once the burning of the fuel *inside* the producer has been started, the air which is used to make the gas keeps up a continuous process of combustion, and a sufficiently high temperature is maintained to decompose the steam and to effect the other necessary reactions.

If there were a shallow fire in the producer and an abundant supply of air, the carbon and other combustible constituents of the fuel would be completely oxidized, and the products of this complete combustion would be incombustible and useless as a gaseous fuel. If, however, there is a considerable depth of fuel in the producer (as there should always be in practice) there will be an excess of highly heated carbon, and this will react on the carbon dioxide and reduce it to carbon monoxide, thus: $CO_2+C = 2CO$. Carbon monoxide may also be formed by the direct combination of carbon with oxygen, thus: $2C+O_2 = 2CO$. Actually both these reactions may and probably do occur. It will be seen therefore that one of the chief functions of a gas-producer is to bring about a partial combustion of the fuel, so that the resulting gas may be combustible. The proportion of combustible to incombustible gas necessarily depends on the fuel used and on the actual conditions of working.

The final result of the complete combustion of carbon is the same whether it takes place all at once in an open fire, or whether carbon monoxide is first formed in the producer, and is afterwards burnt to carbon dioxide. Theoretically when carbon is converted to carbon monoxide in the producer about 30 per cent. of the heat of combustion of the carbon is liberated; the remaining 70 per cent. will be liberated when the carbon monoxide is afterwards burnt to carbon dioxide in a furnace, engine, etc. It should however be understood that all the heat set free in the producer need not be lost; some will be lost by radiation and conduction (say about 8 per cent. of the heat of combustion of the fuel), but a large proportion will be carried away in the form of sensible heat by the gas, as the latter leaves the producer at a high temperature; and if the gas can be used while it is hot, not much of this sensible heat will be lost. The amount of the loss will depend on the extent to which the gas is cooled before it is used. Theoretically, there is no reason why the use of producer-gas instead of solid fuel should necessarily involve a loss of part of the heat available by the direct combustion of the solid fuel, although a considerable proportion of that heat is liberated during the conversion of the solid fuel into producer-gas. In practice, however, this cannot be fully realized,

FIG. 1.—*Bischof*, 1839.

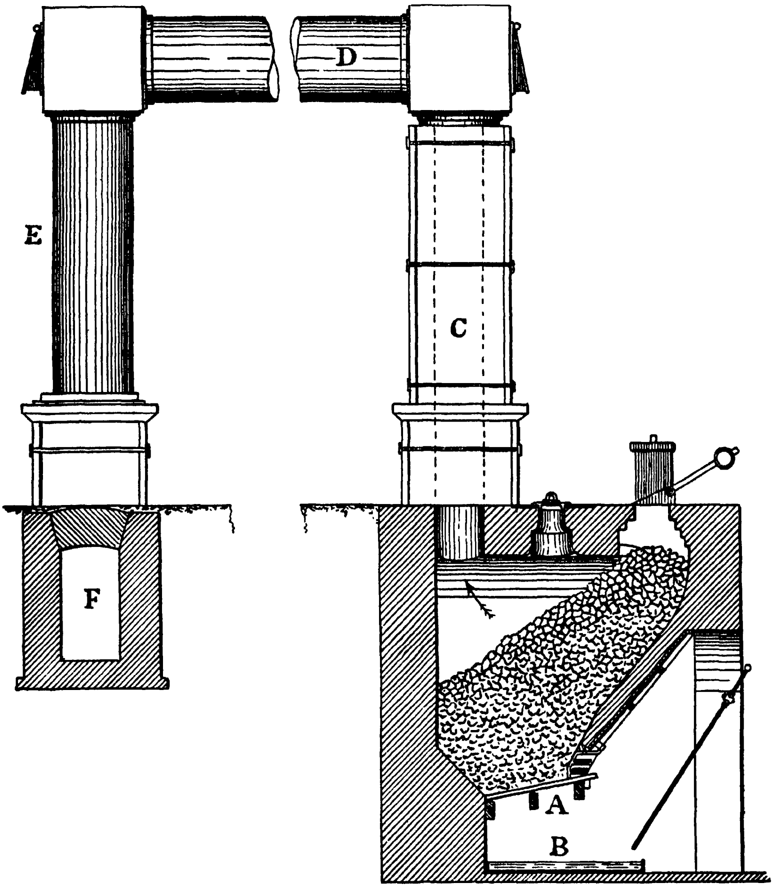


but it may be approached. The chief difficulty lies in the fact that all the carbon dioxide cannot be reduced to carbon monoxide, that there must be some loss of heat by radiation, and that it is not possible to convey sensible heat from one point to another without loss, especially when the temperatures are high. In furnace work, when the furnace is close to the producer, the loss of sensible heat is small; but when the gas is used for engines or for heating work requiring small cocks and burners, it must be washed and scrubbed, and as this involves cooling there is a considerable loss of sensible heat; moreover the gas for an engine must necessarily be cool, apart from cleaning, so that a given volume burnt in the cylinder may contain as large a proportion of heat energy as possible.

It will presently be seen that when the air used for making gas in the producer is mixed with steam, the heat losses will be reduced, but before dealing with this, the working of a producer in which air only is used will be considered, as in Fig. 1. This was the first internally fired gas-producer known, and was invented by an Austrian named Bischof in 1839. It was used in connection with a metallurgical furnace, and the chimney of the latter caused a draught which drew in air at A, A, and through the fire bars B, the gas leaving at D. Fuel was put in at C. No steam was used. The author cannot find an analysis of the fuel used or of the gas made, but he would mention incidentally that some time ago he experimented with a small producer using air and coke (without steam). The gas made contained CO 32·6, H 1·0, CO_2 1·4 and N 65 per cent. by volume, and the calorific power was only 115 B.Th.U. per cubic foot N.T.P. (at normal temperature and pressure). As it is probable that bituminous coal or lignite was used in the Bischof producer instead of coke, it is most likely that the gas made in it had more hydrogen, but also more CO_2. It is tolerably certain that the calorific power of the gas made in this producer must have been low, it would also appear that the gas was burnt in the furnace with cold air; it is therefore not surprising that the results were disappointing. There was also trouble with clinker, and this must have been so because the temperature in a producer worked with air only is excessively high.

The next stage in development was the Siemens producer, Fig. 2, designed in 1861. A novel and ingenious method was

FIG. 2.—*Siemens*, 1861.



adopted for obtaining the necessary in-draught of air and for causing the gas produced to flow to the furnace. From the producer there was a vertical uptake C, usually built of brickwork, and from the top of this there was a long horizontal iron tube D of large diameter, in the direction of the furnace; at the furnace end of the tube there was another vertical tube E leading to the gas flue F of the furnace. The hot gas rose from the producer and as it passed through the tubes D and E its temperature fell; consequently its density was greater at the furnace end, and this caused a siphon action so that there was a suction which caused an in-draught of air through the fire bars A. For our present purpose the chief point of interest is that there was water at B in the bottom of the producer, and as this was vaporized by the heat of the fire above, aqueous vapour mixed with the air and was drawn into the fire.

This addition of water vapour was an important departure; let us consider its effect. When steam (H_2O) interacts with carbon at a sufficiently high temperature it is decomposed, and an equal volume of hydrogen is produced; the oxygen of the steam combines with the carbon to form either carbon monoxide ($H_2O+C = H_2+CO$) or carbon dioxide ($2H_2O+C = 2H_2+CO_2$), according to the conditions under which the reaction takes place. These reactions cause a large absorption of heat, and the addition of even small quantities of steam to the air-supply of a producer reduces the working temperature. Part of the sensible heat is also absorbed, so that the gas leaves the producer at a lower temperature than is the case when air alone is used; the heat so absorbed is stored up in the gas, and is again set free when the gas is burnt. In other words, the effect of the presence of steam in the air-supply is that a smaller proportion of the total heat of combustion of the fuel is liberated in the form of sensible heat in the producer, and a larger proportion is represented by the heat of combustion of the gas. In practice it is soon seen that, when steam is used, the top of the fire is darker than when no steam is used. It should however be clearly understood that, from the point of view of the heat quantities involved, the use of steam in a gas-producer is simply a means of absorbing the sensible heat developed by the partial combustion of carbon, and storing it for future use.

Obviously, there can be no actual increase of the total amount of heat which can be obtained from a given quantity of fuel.

Besides avoiding excessive heat in the producer, the use of steam has the further practical advantage that a gas of greater calorific power can be obtained than is possible when air alone is used. The following is an analysis of the gas made with bituminous coal in the producer, Fig. 2 (page 320).

	Percentage by volume.
Carbon monoxide	23·7
Hydrogen	8·0
Methane	2·2
Carbon dioxide	4·1
Oxygen	0·4
Nitrogen	61·5

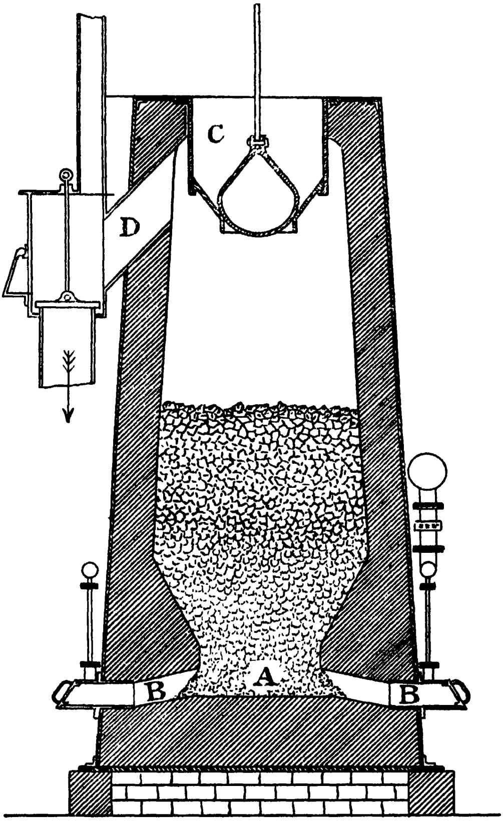
It is probable that the quantity of aqueous vapour which entered the fire in this producer was small, and that some of the hydrogen was derived from the hydrocarbons in the fuel, but the effect of the aqueous vapour is noticeable.

The proportion of steam which should be used to obtain gas of the highest calorific power can be determined theoretically, but in practice this question is materially affected by the nature and composition of the fuel used.

In 1871 Tessié du Motay introduced the producer, Fig. 3. The leading feature of this was a solid hearth A without grate of any kind. Air and steam at pressure were admitted through the channels B,B, of which there were several in the plan view; the fuel was put in through the hopper C, and the gas-outlet was at D. This producer was extensively used in France and in the United States.

In 1876 Brook and Wilson introduced a producer which also had a solid hearth, and air was injected by a jet of steam at pressure. This formed the basis of the well-known Wilson producer which has been used extensively for furnace work. The composition of the gas made in this producer with Durham coal is given by Messrs. Pattinson and Stead as follows :—

FIG. 3.—*Tessié du Motay*, 1871.



	Percentage by volume.
Carbonic oxide	26·8
Hydrogen	11·5
Marsh gas	1·4
Carbonic acid	4·0
Nitrogen	56·1

From time to time various modifications and improvements were introduced by Siemens, Mond, Duff, the author, and others, but the examples he has given are sufficient as types to show the development of the gas-producer used for making semi-water-gas or mixed-gas. Among these modifications may be mentioned the rotating hearth, and the sloping or conical grate with water-bottom, for the removal of clinker and ash while working. The former is useful for a low-grade fuel with a high percentage of ash, but the latter is more simple and better with coal of average quality. Continuous automatic feeding has also been tried, but it has not been so successful in practice as was at first expected. Bituminous coal usually cakes more or less, and must be poked from the top whatever the system of feeding may be.

In the author's own producers of the steam-jet pressure type (with superheated steam) the average composition of the gas made in eight different sizes of producers has been as follows:—

	Percentage by volume.
Carbon monoxide	25·17
Hydrogen	18·19
Carbon dioxide	5·98
Nitrogen, etc.	49·36

In all these tests the gas was made with anthracite which yields less hydrogen than bituminous coal, the increase of hydrogen in the gas (derived from the steam) is therefore very marked compared with the analysis for Fig. 2 (page 320). The weight of steam decomposed varied from 0·5 lb. to 0·7 lb. per pound of fuel gasified.

In the Mond producer, where an excess of steam is used to favour the production of ammonium sulphate, the composition of the gas is as follows *:—

	Percentage by volume.
Carbon monoxide	11
Hydrogen	29
Methane	2
Carbon dioxide	16
Nitrogen	42

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* Proceedings, I. Mech. E., 1901, p. 73.

In this case the hydrogen has been raised to 29 per cent., but the carbon dioxide has also risen to 16 per cent., and clearly from the heat efficiency point of view too much steam has been used. The weight of steam sent into the producer was over 2 lb. per pound of fuel gasified.

When the author first used producer-gas to work gas-engines the compression pressures were low compared with those now in use, and it was considered important to have as high a percentage of hydrogen as possible, as it insured the prompt ignition of the charge in the cylinder. Much higher compressions are now used, chiefly because they raise the heat efficiency of the engine; and as the mixture of gas and air is more highly compressed it is ignited more readily. It has therefore become less important to have a high percentage of hydrogen; in fact it is now considered by many to be a drawback, as there is then greater risk of pre-ignition. From the engine point of view it is better to limit the quantity of steam, but, for the practical working of the producer, it is still desirable to use a liberal quantity to check the formation of clinker and to reduce the loss of sensible heat. It is difficult to meet these somewhat conflicting ideals, and in practice a sort of compromise is effected by having about 12 to 15 per cent. of hydrogen in the gas.

For large furnace work it is often best to have the gas as dry as possible when it reaches the furnace, as the presence of steam lowers the flame temperature. For such work the temperature of saturation of the air-blast for the producer usually varies from about 40° to 60° C. (104° to 140° F.), but this depends a good deal on the size and character of the coal used in the producer.

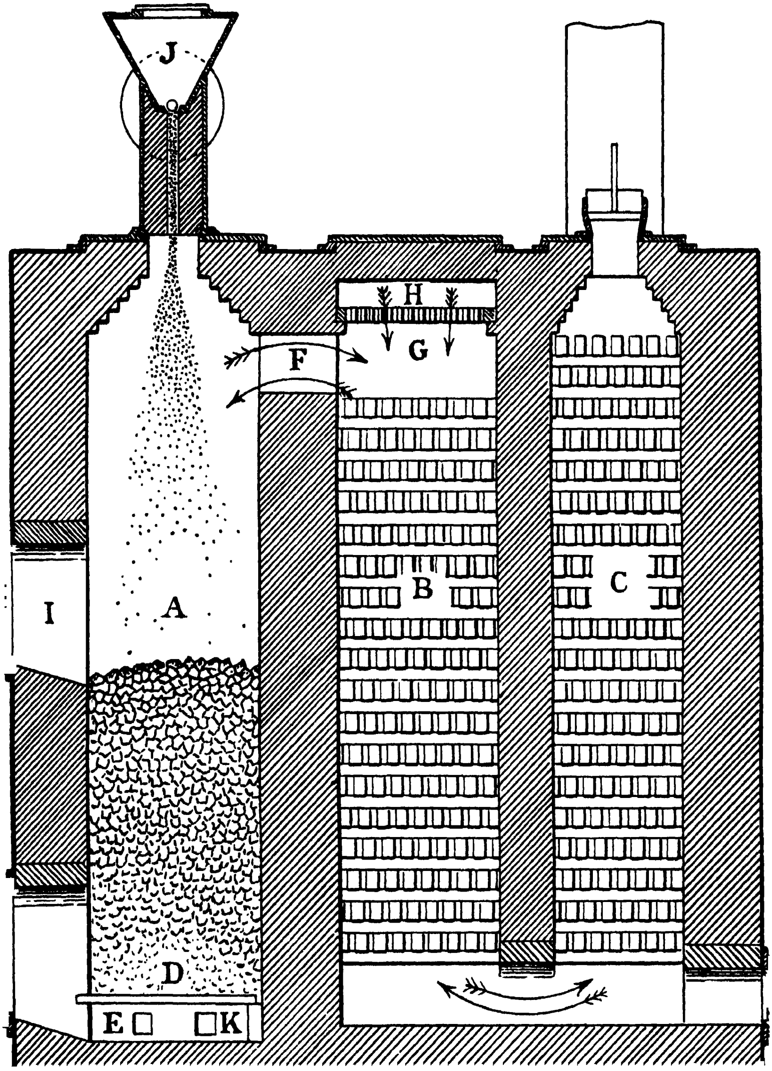
About 1874 Lowe of the United States made a new departure altogether, and produced what is technically known as "Water-Gas." His producer is shown in Fig. 4 (page 327). It consisted of a producer A, and two superheating chambers B and C filled with loose fire bricks. The fire was built up with anthracite or coke on the grate D, and was blown up with air at pressure entering at E. The gas thus produced left the outlet F, and at G it met a secondary supply of air (through the grating H) with which it was burnt; the flame and hot products of combustion passed downwards through the superheater B and upwards through C, and afterwards escaped as a waste product. In this way the brickwork in B and C became highly heated, and as soon as this was the case the two air supplies were shut off, and steam at pressure was admitted at the top of C. It passed downward through C and upward through B, and then through F into the producer A, where it was decomposed on passing through the mass of incandescent fuel. The solid fuel resting on the grate D was put in through the doorway I; but in addition to this, powdered fuel was sometimes fed in automatically from the hopper J during the period when steam was being admitted. This powdered fuel was met by the currents of highly heated steam, and part of the steam was then decomposed before it reached the incandescent mass. The other usual reactions occurred, and the gases formed left the producer at K.

One effect of sending steam only into the producer was to lower the temperature of the fire, and after a few minutes it was necessary to stop the steam-supply and turn on the air-blast again. The gases produced during the period of blowing up with air served to heat the chambers B and C, but they afterwards escaped at a high temperature, and this heat was lost altogether unless it could be applied to some external work. Apart from this, the intermittent production of the water-gas is a drawback, and it is usual to pass the gas into a gas-holder and to connect two or more producers to the latter. The heat efficiency is necessarily low as so much of the gas produced is wasted, and the water-gas loses its sensible heat before it can be used. On the other hand the flame temperature and the calorific power of the water-gas are high, and it is often used as a basis for lighting gas. Its composition is usually given as follows:—

	Percentage by volume.
Carbon monoxide	44
Hydrogen	48
Carbon dioxide	4
Nitrogen	4

FIG. 4.

Lowe, 1874.



It should however be remembered that the composition varies considerably between the times of starting and stopping each admission of steam, so that the above figures can only be attained at certain periods.

Messrs. Dellwik and Fleischer have devised a modified water-gas apparatus, in which the period of air-blow is greatly reduced. Professor Vivian Lewes says*: "In the old 'European' process it was necessary to blow for nearly ten minutes to bring the fuel bed up to the right temperature, whilst the period during which the incandescence was sufficiently great to decompose the whole of the volume of steam used limited steaming to four to five minutes, whereas in the Dellwik process the period of blowing rarely exceeds two minutes, and it is possible to steam for from seven to ten. according to the condition of the fuel." He gives the carbon dioxide as only about 5 per cent., and explains that this is due to regulating the flow of steam so that "even at the extreme end of the run there shall be no excess of steam to oxidize the carbon monoxide to dioxide." He adds that samples of the gas taken during the process of making had the following compositions:—

—	1	2	3
Hydrogen	52·43	50·09	52·76
Carbon monoxide . .	38·30	39·95	37·50
Carbon dioxide . . .	4·73	5·38	4·08
Oxygen	0·74	1·22	0·46
Nitrogen	3·80	3·36	5·20

The Loomis-Pettibone plant is another modification of a water-gas plant. In this there are two producers through which air is drawn downwards by an exhauster, and after passing through scrubbers, etc., the producer-gas thus formed is sent into a gas-holder. At intervals the air-supply to one of the producers

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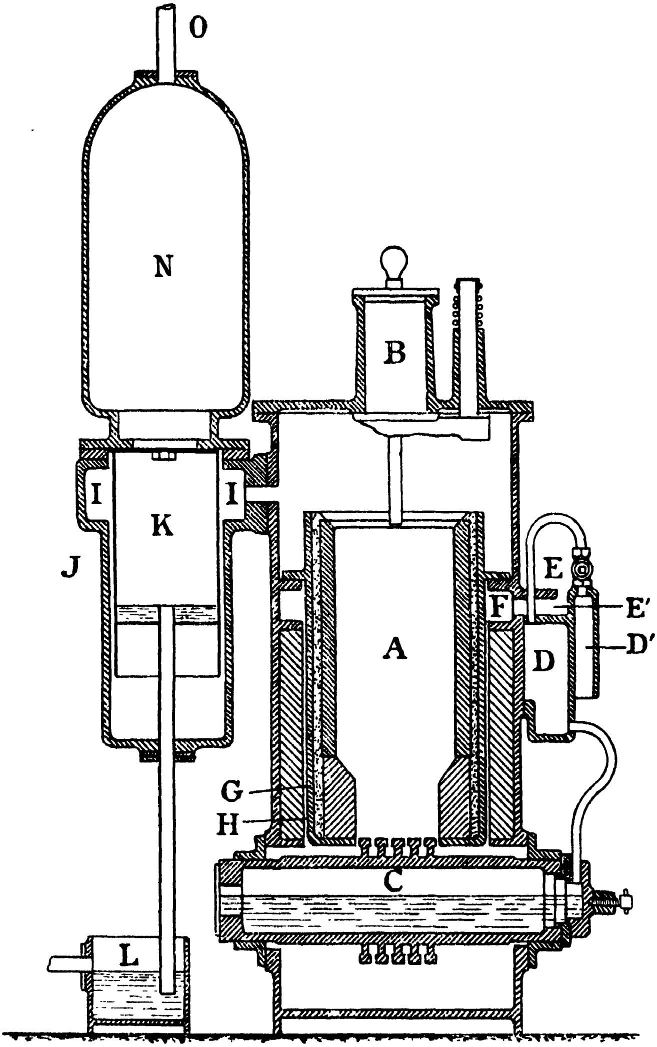
* "Liquid and Gaseous Fuels," page 230.

FIG. 5.

Bénier, 1894.



is closed and steam is admitted at the bottom. A mixture of producer- and water-gas is then formed, and this is sent into the gas-holder to mix with the producer-gas already there. As the process is intermittent and variable, it is necessary to mix the gases in a gas-holder to get something like an average result. Mr. Nisbet Latta says,* "The best results or high efficiency of gas obtained from this process for power purposes is found with the gas approximating 105 B.Th.U. in value, this usually representing about 5 per cent. of water-gas to 95 per cent. of producer-gas in the total mixture."

A very interesting type of gas plant, technically known as the Suction Plant, has now to be considered. It has been seen that, in some of the early gas-producers used for furnace work, air was drawn into the producer by suction, instead of being forced in under pressure, as in producers of later date. In recent years the idea of working the producer by suction, instead of by air-pressure, has been reverted to, chiefly in connection with gas-engines. As early as 1862 Dr. Jacques Arbos of Barcelona devised a combination of gas-plant and gas-engine, in which the latter drew gas direct from the producer. It was not a very practical arrangement and the charge of gas and air was not compressed before ignition, but it deserves to be mentioned as one of the early suction plants devised. The first to give effect to this idea in a practical way, with a compression engine, was M. Léon Bénier of Paris, in 1891. He afterwards introduced some improvements, and the plant shown in Fig. 5 (page 329) represents what he used in 1894. In this A is the gas-producer, B the feeding hopper, C a revolving grate containing water, D a chamber to receive steam produced in C, D′ a chamber open at the bottom to receive steam from D and allow it to expand to atmospheric pressure, E the air-inlet, E′ a passage for steam from D′, F a mixing chamber for steam and air at atmospheric pressure, G the inner casing of producer, H an annular space for steam and air to pass from F to the bottom of fire, the steam and air being heated on the way, I an annular space for hot gas from the producer, J a cylinder with water inside, K an inner cylinder of which the lower end is dipped in water in J so as to form a washer for the gas, with an overflow tank L, and N a chamber to receive gas, with outlet O at the top.

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* "American Producer-Gas Practice," page 114.

The engine had a suction-pump by the side of the motor cylinder, and this pump was connected by a pipe with the outlet O. As soon as the fire was lighted it was blown up with a hand-power fan, and when the gas was good enough to work the engine the latter was started. The pump on the engine then drew gas from the producer and forced it into the motor cylinder. This suction of gas from the producer lowered the pressure in the latter, and consequently air from the outside flowed in through the inlet E. The steam or water-vapour formed in C mixed with the air before the latter entered the fuel column, and both steam and air were drawn together into the fire. The volume of air drawn in varied with the rate at which gas was consumed in the engine; in other words the rate of producing the gas was governed automatically by the engine itself, and both the gas-holder and the independent boiler were dispensed with altogether. As this plant and those of which it is the type work by suction they are now generally known as *suction plants*, to distinguish them from pressure plants worked by steam and air at pressure.

The gas was poor in quality, and there was the friction of the pump as well as other drawbacks. The fuel consumption with this combination of gas-plant and engine* was therefore higher than with a pressure plant and its independent boiler. It was seen however that the working of a plant by suction in combination with an engine would have distinct advantages if the practical details could be worked out satisfactorily. Several engineers gave their attention to the subject, and the next step of importance was to do away with the pump on the engine, and to use the suction of the engine itself to draw gas from the gas-plant. This reduced appreciably the loss from friction. Also various improved methods have since been devised for producing the steam required, and for removing the clinker formed in the producer. The production of the steam required to make good gas and to keep the temperature of the fire low enough to prevent the formation of an excessive amount of clinker presents many difficulties. Some makers have a water vaporizer inside the producer, sometimes near the bottom of the fire, but more often near the top; and they heat it by the fire or by the hot gas which leaves the fire. In some cases both these sources of heat are used. On the other hand, some makers prefer to have the vaporizer outside the producer and to heat it by the sensible heat of the gas after it has left the producer. The latter system has the advantage of cooling the gas more, but the amount of steam raised is less than in the other systems, and there is the risk that the gas will not always be hot enough to make the full quantity of steam required. This not only affects the percentage of hydrogen, etc., in the gas, but has an important bearing on the formation of clinker. It is in fact essential that there should be a sufficiency of steam, but this point does not always receive the attention it deserves.

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* "Moteurs à Gaz," Vol. 3, p. 186; Ency. Brit., Vol. 28, p. 606.

Apart from producing a sufficient quantity of steam when the maximum volume of gas is required, there is the further necessity for regulating the quantity of steam drawn into the fire when the load on the engine is variable. It has been supposed that when less gas is produced, that is, when less air is drawn into the fire, the lowering of temperature which follows causes less steam to be produced, and that in this way the quantity of steam produced is proportional to the quantity of gas required. This is only partly true, as actually the temperature of the fire does not vary as quickly as the load on the engine may vary, and although there may be a considerable fall in the load, there is usually heat enough in the fire to produce more steam than is then desirable. If this excess of steam continues, it not only causes an excess of carbon dioxide to be formed, but it damps down the fire. Then, when the load is suddenly increased, the temperature of the fire is not high enough to give effect to the necessary reactions, and the gas is not good enough to develop the power required. Some makers of suction plants try to get over this difficulty by having regulating valves worked by the engine, by means of which the admission of steam to the fire is governed by the engine. Some merely allow a vent in the vaporizer for the excess of steam to escape when the load is reduced; others have used the suction of the engine to draw water into the vaporizer in very small quantities, just enough at each suction-stroke to give the steam required for the quantity of gas to be consumed. This can only be done provided the vaporizer flashes the water into steam; if the vaporizer holds a body of water, as in a boiler, steam is given off continuously.

To compare the gas made in a suction plant with that made in a steam-jet pressure plant of the same power, the author gives the results, Table 1, obtained with a 40 b.h.p. plant of each type working with anthracite, and in a separate column he gives the average results of seven different pressure plants of various sizes ranging from 8 to 300 h.p.:—

TABLE 1.

Composition of Gas. (Per cent. by volume.)	Suction Plant. 40 b.h.p. (hot start) 1.	Pressure Plant. 40 b.h.p. (hot start) 2.	Pressure Plant. Average of 7 plants of different sizes (hot start) 3.
Hydrogen . . .	15·64	19·8	17·36
Methane . . .	1·16	1·3	1·20
Carbon monoxide . .	20·13	23·8	25·55
Carbon dioxide . .	6·09	6·3	5·77
Oxygen	0·74	—	0·30
Nitrogen . . .	56·24	48·8	49·82
Calorific value (higher scale)			
B.Th.U. per cubic foot .	135·3	164·4	161·0
Calories per cubic metre.	1,204	1,463	1,432

1. Proceedings, Inst. C.E., 1904, Vol. clviii, p. 322.
2. *Ibid.*, 1901, Vol. cxliv, p. 282.
3. ,, ,, ,,

From this it appears that the calorific power of the pressure-gas is approximately 20 per cent. higher than that of the suction-gas. In the latter the percentages of hydrogen and carbon monoxide are lower, while the percentage of nitrogen is higher; but less air is required for combustion of the suction-gas, and a rather larger volume of the latter (compared with pressure-gas) can be used for each explosion in an engine-cylinder of given size. A further point is that there is rather more fluid friction to allow for when suction-gas is used. The practical result is that there is a loss of about 5 per cent. in the maximum power of the engine when worked with suction-gas. This is not important for small engines, but for those of larger size it must be considered. On the other hand, the heat efficiency of a pressure plant with independent boiler must necessarily be lower than that of a suction plant which produces its own steam without an independent boiler. If the steam for the pressure plant were raised by the sensible heat of the gas produced, as is sometimes done, the heat efficiencies of the two types of plant would then be nearly alike.

In considering the two types of plant for engine work, our general conclusions may be as follows:—A suction plant has certain practical advantages: it costs less and occupies a smaller ground space, but the gas made in it is not so strong as in the older form of pressure plant, and in some cases this advantage of the latter is important. The fuel consumption per h.p.-hour and the labour required are about the same in both types of plant, provided the steam required is raised without an independent boiler. The consumption of water is the same in both types. It is also worth mentioning that where there are several engines to serve, the arrangement of the gas-pipes is greatly simplified, and their cost is proportionally reduced, also the engines can be started more readily, when the gas can be taken from a small gas-holder instead of from several suction-plants.

There are many interesting questions which affect the working of an engine when suction-gas is used, but they are beyond the scope of this Paper, and rather reluctantly the author refrains from discussing them. It is however desirable to consider the variations in the quality of suction-gas when the engine is working with light and variable loads. It has been seen that in a suction plant the *quantity* of gas produced is regulated by the action of the engine, as there is a draught of air and steam through the producer every time gas is admitted to the engine. If the latter is of the Otto type, the gas-valve opens at every fourth stroke when there is a full load; but when the engine is governing the valve is opened less frequently, and consequently there are longer intervals between the intakes of air which are drawn into the producer. It is therefore important to consider how this varying quantity of air affects the condition of the fire and the composition of the gas.

It is safe to say that no producer makes gas of equal calorific power at all rates of production, and speaking generally it may be assumed that the best gas will be made when the producer is worked uniformly at its maximum, or nearly its maximum capacity. At any rate of production considerably less than the maximum, the calorific power of the gas will be lower. To test this practically, the author had some trials made with a 40 b.h.p. engine working with a full load and with no load at all. The gas was made with ordinary gas-coke; the full-load test was made when the fire was in good working order, and the no-load test was begun by throwing off the load and the belt, while the engine continued to run at the same speed. The no-load test lasted three quarters of an hour. The following analyses represent the average composition of the gas in each test:—

	Per cent. by volume.	
	Full load.	No load.
Carbon monoxide	27·65	22·4
Hydrogen	9·85	7·0
Carbon dioxide	3·8	4·9
Oxygen	0·3	0·5
Nitrogen, etc.	58·4	65·2
Calorific power.		
B.Th.U. per cubic foot	128·9	101·0
Calories per cubic metre	1,147	899

The author had this further tested at Derby (1906) during the trials of suction plants made on behalf of the Royal Agricultural Society. To test their working with widely different loads, the Judges ordered the plants to be run for two hours with no load immediately after starting up in cold producers, then for one hour at full load, then for another hour with no load, and afterwards for successive periods of one hour each with one-quarter, one-half, and full loads. The author took this opportunity to have numerous samples of the gas taken in one of his own 20 h.p. plants working with small anthracite under these varying conditions, and the following are the results :—

TABLE 2.

Conditions of working.		CO.	H_2.	CH_4.	CO_2.	O_2.	N_2.	Calorific power.	
								B.Th.U. per cubic foot.	Calories per cubic metre.
First hour.	No load .	10·2	11·05	2·15	11·2	0·1	64·7	102·7	913·9
Second „	„ „ .	12·45	12·15	2·0	10·1	—	63·3	105·8	941·5
Third „	Full load .	22·25	15·9	1·95	5·25	0·1	54·65	152·3	1355·3
Fourth „	No load .	18·3	13·6	1·2	9·05	0·3	58·55	122·8	1092·7
Fifth „	¼ load .	20·0	11·8	0·75	8·35	0·1	59·05	117·5	1045·6
Sixth „	½ load .	20·9	14·0	0·7	7·7	—	56·7	127·7	1136·4
Seventh „	Full load .	21·5	14·5	1·2	7·6	—	55·2	136·8	1217·3

As was to be expected, the gas contained smaller percentages of carbon monoxide and hydrogen, and larger percentages of carbon dioxide and nitrogen during the no-load periods. It will also be noticed that while the gas made with no load on the engine, immediately after starting in a cold producer, had a low calorific power and did not materially improve while the producer continued to work without load, yet after the producer had worked for a time at full load, and had become thoroughly heated up, with a good depth of bright fire, it gave gas of considerably higher calorific power than before when the load was again removed. The explanation of this is mainly a question of temperature. At full load the intermittent draughts of air through the fire follow one another in quick succession, and the fuel is maintained at a high temperature; when there is no load there are comparatively long intervals between the intakes of gas, so that in the producer there are short, sharp suctions of air with intervals between them during which the temperature of the hot fuel falls. After the producer has been working for a little time at full load, the depth of bright fire is sufficient to make good gas during each of these periods of suction, and the temperature does not at once fall; so that the producer continues to make fairly good gas for a considerable time after the load has been removed.

If the producer were worked by the continuous suction of a fan, instead of by the frequent intermittent suctions of an engine, the quality of the gas would be practically the same under full load, the volume of air drawn in per minute being the same for a given power. During the no-load period the effect would not be quite the same. With a fan there would be a steady draught of the volume of air required, and there would be a shallow zone of fire near the grate, which would be maintained at a sufficiently high temperature to make good gas; and gas of good quality would be produced as long as this hot zone was sufficiently deep in relation to the size of the fuel. If the air for the producer were drawn in by an engine without load a greater depth of fuel would be heated by reason of the more rapid draught of air through the fire; but a good deal of heat would be dissipated before the next suction. This points to the importance of maintaining the temperature of the fire as high as possible when the producer is worked at a reduced load by the suction of an engine; and a step in this direction is to reduce the quantity of steam proportionally to the volume of air drawn in. If the production of steam is continuous while the indraught of air is intermittent, if follows that after each interval there must be an excess of steam mixed with the air, unless some way of regulating the production or admission of the steam is adopted. If there is too much steam during the light loads, this of itself lowers the temperature of the fire and adds to the trouble caused by the small amount of air drawn in. If the air is heated before it reaches the fire, this also will assist to maintain the temperature required. It is not easy to fulfil all these conditions without complicating the apparatus, but it is well to consider what will give the best results, so that a near approximation may be obtained.

It is well known that, after an engine has been working under a light load for some time with a suction plant, there is risk of stoppage if the full load is put on suddenly. Moreover, when this occurs, it is often attributed to an insufficient supply of gas. This is a mistake, as the volume of gas necessarily varies directly in proportion to the load on the engine; it is the *quality* of the gas which is at fault, and the explanation of this fact is not far to seek. It has been seen that during the light-load periods the temperature of the fire falls, and that for a few moments after the full load has been put on there is too little hot fire; so what there is, is not hot enough, to effect the necessary chemical reactions. There is too little hydrogen, and not enough of the carbon dioxide is reduced to the monoxide. The remedy is to put on the full load more gradually, so that the engine may be kept running at full speed in spite of the weakness of the gas, and to check the admission of air to the cylinder; the fire in the producer will recover rapidly, and there will soon be a full supply of gas of good quality.

To realize what occurred, the author had the following tests made. An engine and suction plant were worked without a load for 70 minutes, and then the full load was put on suddenly; the adjustments of the gas and air supplies to the engine were not altered throughout the tests, so that the varying mean pressures obtained were due solely to variations in the quality of the gas. Table 3 gives the results:—

TABLE 3.

Time.	Mean pressure of indicator diagram.
2.50 p.m. load off . . .	76 lb. per square inch
3.5 ,, ,, . . .	74 ,, ,,
3.15 ,, ,, . . .	74 ,, ,,
3.25 ,, ,, . . .	73·5 ,, ,,
3.45 ,, ,, . . .	decreasing
4.0 ,, full load on . .	increasing 84·5 lb. per square inch

The last three diagrams were taken in succession, immediately after putting on the full load. While the first of these was being taken the explosions became weaker and weaker; while the next was being taken they became stronger and stronger; and when the last was taken the fire in the producer had regained its normal condition, and the explosions were regular and good. Those who care to consider these tests more closely will find reproductions of the indicator diagrams in the author's book on "Producer Gas."

As bearing on this question, he might mention another test which was made. The engine was run without a load, and then a brake was applied, and in a short time the engine stopped. Immediately after it stopped, a sample of gas was drawn from the main near the engine, which on analysis gave the following composition:—

	Percentage by volume
Carbon monoxide	16·2
Hydrogen	11·9
Methane	0·25
Carbon dioxide	9·4
Oxygen	0·9
Nitrogen	61·35

The calorific value was only 99·4 B.Th.U. per cubic foot, or 88 calories per cubic metre.

The extreme case was taken of an engine running for some time without a load, and then having the full load applied suddenly. This would seldom occur in ordinary practice, and the variations would not be so noticeable under the ordinary variations of load; but the principle holds good, and it is evidently important to maintain, as far as possible, a sufficient depth of fuel at a sufficiently high temperature for whatever variation of load may be put on the engine.

At the Derby trials referred to on page 336 the numerous samples of gas taken gave the following *average* analyses (per cent. by volume) for full and half loads :—

	Full load.	Half load.
Carbon monoxide	21·95	18·9
Hydrogen	13·85	14·05
Methane	1·55	1·60
Carbon dioxide	7·2	8·05
Oxygen	0·1	0·05
Nitrogen, etc.	55·35	57·35
	100·0	100·0
Calorific power.		
B.Th.U. per cubic foot	139·7	130·5
Calories per cubic metre . . .	1,243·5	1,161·5

It will be seen that at half load there is less CO and more CO_2 and N, owing to the lower temperature of the fire in the producer. Consequently the gas is weaker, but it is satisfactory to note that the difference is not great between full load and half load. It should also be understood that there is no difficulty in working a suction plant with a steady load which is only a small fraction of its maximum; the difficulty arises when a considerable increase in the load is put on suddenly, after working with a low load.

Analyses of suction-gas made in small plants have been given, and the author now gives the composition of the gas made in a 350 b.h.p. suction plant of his design. The fuel used was "carbonite" from Huddersfield, and during an ordinary day's run the average composition of the gas was:—

	Percentage by volume.
Hydrogen	7·92
Carbon monoxide	30·38
Carbon dioxide	3·04
Oxygen	0·42
Nitrogen	58·37

The percentage of hydrogen was low, but the CO was high, and with its high compression the engine worked well.

It has been shown that producer-gas can be obtained with almost any kind of carbonaceous fuel, and that when tarry vapours are mixed with the gas they can with advantage be burnt with it in furnaces; but for engines and small heating work all tarry vapours must be eliminated before the gas reaches the valves, cocks, etc. Hitherto this has been done by centrifugal tar-extractors, washers, and other apparatus which add to the complication and cost of the plant. Some attempts have been made to draw off the tarry vapours from the upper part of the producer and to return them to the lower part of the fire where combustion takes place, but so far as the author is aware none of these plants have been altogether successful, as some of the tarry vapours go forward with the gas and must be removed by extractors or washers, etc. Another method of fixing the tarry vapours is to work the producer with a down-draught instead of an up-draught. In this way the tarry vapours from the raw fuel (put in at the top) are compelled to pass through the whole depth of the fire so that they may be converted into fixed gases. It is almost impossible to do this effectually in continuous work, owing to the difficulty of maintaining a suitable temperature. It is also difficult to burn the fuel completely, and usually there is an accumulation of small carbon or coke, mixed with clinker and ash, in the lower part of the producer.

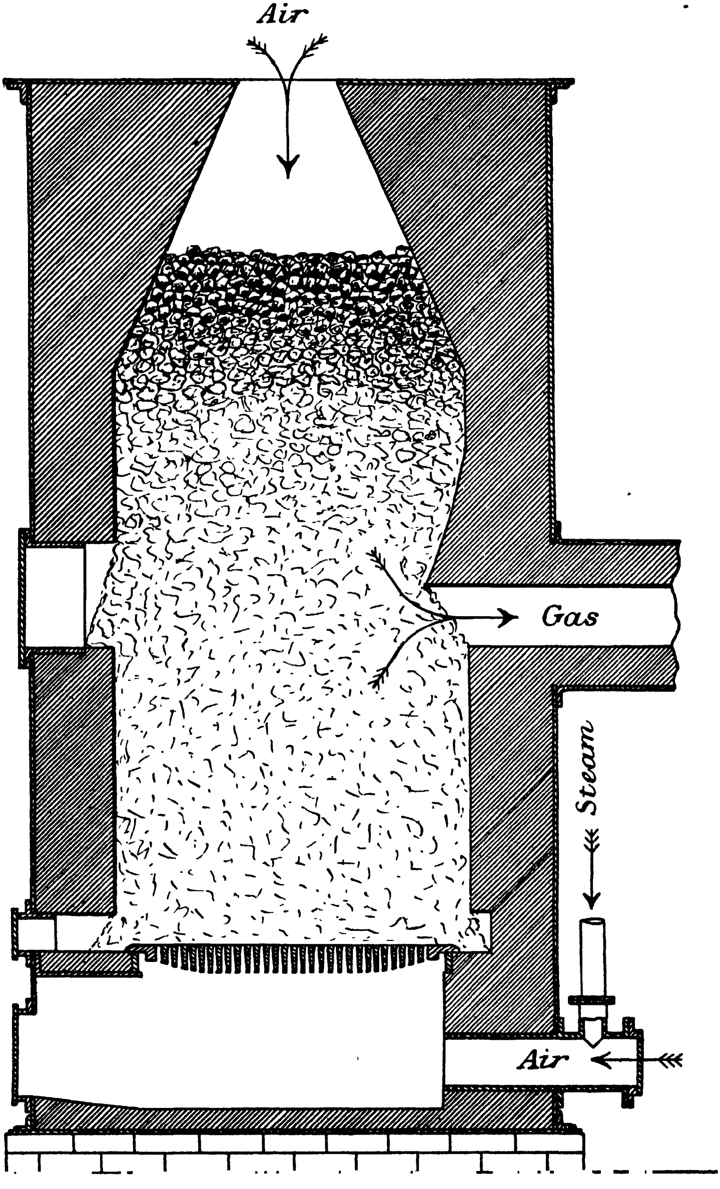
The author has always held to the opinion that the tarry vapours should be got rid of in the producer itself, and that it cannot be right to let tarry gas leave the producer, and then be obliged to remove the tar by extractors, etc. With this in view, he designed, in 1903, the producer shown in Fig. 6. This producer is double-acting, that is, air is drawn in through the top and through the bottom of the fuel column. The coal is put in at the top, and the upper part of the fire burns downwards. The hydrocarbons are distilled off and various useful reactions occur; the coke which remains sinks down gradually into the lower part of the producer. The coke is there converted into ordinary producer-gas by the upward current of air (accompanied by steam) which is drawn in at the bottom. The mixture of gases leaves the producer through an outlet about halfway between the top and bottom.

When working with ordinary bituminous coal, or with lignite and several other varieties of fuel, *there is no tar;* it is disposed of altogether in the producer, and no mechanical or other tar extractor is required. After leaving the producer the hot gas passes through an external vaporizer, to cool the gas, and so raises the steam required for making the gas. It then passes through suitable scrubbers and is ready for use in the engine to be worked with it.

This bituminous plant can be worked by the suction of an engine, or when the gas is to be passed into a gas-holder for distribution to several engines, or to heating apparatus, there is an exhauster to draw gas from the plant and deliver it into a holder.

It took a long time to perfect the details of this plant, but one for 500 h.p. was started in October 1908 at the works of Messrs. Kenrick and Sons of West Bromwich, and has been working regularly ever since. The results were so satisfactory that in October 1909 they started a second plant of this type for 700 h.p., and both plants are now serving 13 gas-engines which were previously worked with anthracite pressure-gas. The author has not an analysis of the gas made in the smaller plant, but in the larger one it was as follows:—

FIG. 6.—*Dowson*, 1903.



	Percentage by volume.
Carbon monoxide	23·9
Carbon dioxide	7·2
Hydrogen	16·0
Methane	1·0
Nitrogen	51·9

The calorific power of the gas is nearly as high as that of gas made with anthracite in an ordinary suction plant. The fuel used at West Bromwich had the following composition:—

Fixed carbon	55 per cent.
Volatile matter (other than moisture)	30 ,,
Moisture	8 ,,
Ash	7 ,,

Calorific value 13,400 B.Th.U. per lb.

The coal costs 8*s*. a ton delivered, as against 23*s*. for anthracite. On an average of several months the consumption of bituminous coal was about the same as with anthracite, namely, about 1 lb. per i.h.p.-hour including all standby, cleaning and starting losses. The gas has no tar when it leaves the producer, and none is found in the scrubbers or overflow water; and Messrs. Kenrick have stated that the gas from the bituminous coal is as clean as the anthracite gas previously used. They clean the engine valves only once in about three months.

Among other plants of this type in use Messrs. Faire Brothers of Leicester are now working one for 400 b.h.p., and they find that their engines work as well with it as with the anthracite plant they previously used. In their case they use a coal of the following composition when dried at 212° F.:—

Fixed carbon	57·90 per cent.
Volatile matter	37·50 ,,
Sulphur	1·00 ,,
Ash	3·60 ,,

Moisture 11·10 per cent.
Calorific value 12,100 B.Th.U. per lb.

At first the author thought that these plants would not be suitable for small powers, but more recently he has had a 30 h.p. suction plant of this type working regularly for about eight months, and it has given no more trouble than an ordinary suction plant working with anthracite or coke. The engine-valves were not cleaned for five months.

MM. Boutillier and Cie. of France have a producer in which bituminous coal is forced into the bottom of the fire by means of a screw feed, and, as the producer is worked with an up-draught from a blower, the tarry vapours distilled off at the bottom pass through the incandescent fuel above. Power is, of course, required to send in the coal, and the rate of feed must be regulated to suit the rate of consumption. The author has seen a plant of this type working well with semi-bituminous (*demi-gras*) Belgian coal, containing 12 to 13 per cent. volatile matter. He does not know what the result would be with English coal, which usually contains not less than 30 to 35 per cent. of volatile constituents.

There are many other producers, some of which have points of novelty and interest, but it would not be possible to deal with all of them in a single Paper. Moreover, these details do not affect the principles involved, and, as he stated at the outset, the author has confined himself to certain types so that their leading theoretical and practical points may be more easily considered.

In conclusion, he thinks it will not be out of place to point out that for engine work the standby loss of a steam-boiler is much greater than that of a gas-producer, and the explanation is not far to seek. For a given horse-power the producer is much smaller, and has far less radiating surface than a boiler, it has no water in it to be heated, and in a few minutes it can be worked up to its maximum production after standing almost any length of time. With a boiler, except in the vertical or portable type, there is a large amount of external brickwork to be heated, and there is a considerable quantity of water, even in the tubular type. When the boiler is standing, the water and the brickwork lose heat, and not only more time but more fuel is required to make up this loss than in the case of a gas-producer. Doubtless the heat efficiency of a good boiler is high when it is working to nearly its full capacity, but the reverse is the case when it is standing. Table 4 gives some comparative results:—

TABLE 4.

Steam Power.			Gas Power.	
Type of Boiler.	Maximum h.p. of boiler.	Coal consumed per standing hour.	Maximum h.p. of producer.	Coal consumed per standing hour.
		lb.		lb.
Various . . .	100	14·0	250	5·1
Lancashire . . .	450	*37·5	250	3·9
Babcock and Wilcox .	210	67·0	100	2·1
,, ,, .	210	67·0	250	4·5
,, ,, .	500	180·0	225	3·8
,, ,, .	500	112·0	375	1·8
Niclausse . . .	400	50·0	—	—
Lancashire . . .	400	44·7	—	—
Average . .	—	71·5	—	3·5

* Exclusive of raising the steam-pressure from 90 to 120 lb.

On this basis, if a 200 b.h.p. steam-boiler works 8 hours and is standing 16 hours, and if it consumes 2·5 lb. per b.h.p.-hour, the standby loss will be over 20 per cent. of the total fuel consumed in 24 hours. Under like conditions, if a gas-producer of the same power consumes 1 lb. per b.h.p.-hour, the standby loss will be under 4 per cent. of the total fuel consumed. With a 500 b.h.p. boiler the standby loss will be about 15 per cent., and with a gas-producer under 2 per cent. If one takes the percentage of the

standby loss on the fuel consumed during the working hours, the following results are obtained :—

—	200 b.h.p.	500 b.h.p.
	Per cent.	Per cent.
Steam power	26·8	17·9
Gas power	3·8	2·0

The Paper is illustrated by 6 Figs. in the letterpress.

[*The Discussion on this Paper was combined with that on the Paper by* Mr. E. A. Allcut, *and commences on page* 373.]

THE EFFECT OF VARYING PROPORTIONS OF AIR AND STEAM ON A GAS-PRODUCER.

By Mr. E. A. ALLCUT, M.Sc., *Graduate*, late Bowen Research Scholar, University of Birmingham.

Objects of Research.—The experiments recorded in this Paper were performed during the months of February to April, 1909, on a small gas-producer at the University of Birmingham. The chief object of the research was to determine the influence of varying quantities of steam on the general working and efficiency of a producer plant of small size. The supply of air to the producer was, therefore, kept as nearly constant as possible in all the trials, while the steam supply was varied from nothing to a maximum of 1·14 lb. per lb. of coal. In order to avoid complication and to eliminate all uncertainties of measurement which must necessarily arise from the presence of tar and volatile hydrocarbons, as well as to obtain a fuel as nearly approximating to pure carbon as possible, it was decided to use anthracite peas (of the same quality) throughout the trials.

The steam required for the process was generated within the producer, so that the general conditions closely resembled those under which a modern suction-plant works; the sole exception being that the air was forced into the ash-pit by a fan, instead of being sucked through the plant intermittently by an engine. The conditions were thus kept fairly steady throughout each trial. A good deal of uncertainty seems to exist among the makers and users of gas-producers, respecting the amount of steam that is required to give maximum efficiency and best all-round working. It was therefore hoped that these trials would clear up a good deal of this uncertainty. A series of similar trials were performed in 1906 by Messrs. Bone and Wheeler,* on a 2,500 h.p. gas-plant. It was felt, however, that the conditions under which these trials were performed, were vastly different from those under which most of the smaller plants work, and that it was necessary to repeat them on a small plant with non-bituminous fuel, to gain a more exact idea of the influence of steam upon producers of small capacity. Every factor liable to influence the process of gasification was accurately noted, and the results obtained should therefore be applicable to modern producer practice, and should in addition throw some light on the theory of gas production.

Reactions taking place in the Producer.—A brief consideration of the theoretical principles involved in the manufacture of producer-gas becomes necessary at this point. The true nature of the combustion of solid carbon is still, among scientists, a vexed question. Some chemists hold that with excess of carbon the combustion proceeds in two stages; first of all with the production of carbon dioxide,

$$C + O_2 = CO_2 \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

and then with the reduction of the dioxide on further contact with carbon,

$$CO_2 + C = 2CO \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

Others maintain that the combustion proceeds in a single stage, direct to carbon monoxide,

$$2C + O_2 = 2CO \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

At the bottom of a gas-producer, however, the carbon is never in excess, so that the author is of opinion that the first two reactions probably take place within the producer. However this may be, the final chemical and thermal results of the combustion are the same in each case, so that it is sufficient to confine our attention to the last reaction.

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* Journal, Iron and Steel Institute, 1907, No. 1.

The combustion of 1 lb. of carbon to carbon monoxide is accompanied by the evolution of 4,400 B.Th.U., leaving the other 10,200 B.Th.U. still obtainable to be given out by the gas in the second stage. The gas thus obtained has the following theoretical composition: $CO = 34 \cdot 7$ per cent., $N = 65 \cdot 3$ per cent. by volume. Its calorific value is 118·4 B.Th.U. per cubic foot, and the volume of gas given off per lb. of carbon is 85·9 cubic feet at 32° F. (0° C.). The amount of heat available in the gas is thus 70 per cent. of that present in the original coal, and so the thermal efficiency of the process is 0·7. The evolution of sensible heat, amounting to 30 per cent. of the total heat in the coal, raises the temperature of the producer, and causes trouble in working by the formation of clinker, which obstructs the blast and interferes with an even distribution of air through the mass of fuel. To avoid the production of too high a temperature and other practical difficulties, some of the sensible heat developed may be used to generate steam, to be passed into the producer with the air. This steam may react on its own account with the carbon in the following ways:—

$$C + H_2O = CO + H_2 \quad . \quad . \quad . \quad . \quad . \quad (4)$$

$$C + 2H_2O = CO_2 + 2H_2 \quad . \quad . \quad . \quad . \quad (5)$$

Both these reactions are endothermic; the former to the extent of 4,300 B.Th.U. per lb. of carbon, and the latter to that of 2,820 B.Th.U., so that each of them has the practical advantage of reducing the temperature of the producer. It has been found * that, at a temperature of 1,112° F. and under, the latter reaction takes place, while at temperatures above 1,832° F., reaction (4) is more likely to occur. At temperatures between 1,112° F. and 1,832° F. the two take place simultaneously, the predominance of either being entirely a function of the temperature. It is clear that as equation (4) gives the richer gas, and the greater absorption

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'Producer Gas," Dowson and Larter, page 55.

of heat, it is advisable to work at the highest temperature consistent with practical working. The high percentage of CO_2 in Mond gas is due to the predominance of the reaction expressed by equation (5), which results from the low temperature and excessive steam supply necessary for ammonia recovery. This latter consideration does not enter into the practical working of plants generating less than 2,000 h.p., so that in small plants the steam supply can be cut down to any point consistent with the non-formation of clinker.

The actual conditions inside the producer are by no means as simple as would appear from the preceding reactions. When CO and steam are both present in a gas-producer, the following reversible reaction may be set up—

$$CO + H_2O \rightleftarrows CO_2 + H_2 \quad . \quad . \quad . \quad . \quad (6)$$

This reversible reaction which takes place at temperatures above 932° F. again depends for its balance upon the temperature. At high temperatures (1,832° F.), the left-hand side predominates, and at low temperatures carbon dioxide and hydrogen are formed. At any temperature between 932° F. and 1,832° F. the product of the percentage volumes of CO and steam bears a constant ratio to that of the CO_2 and hydrogen. Oscar Hahn * gives the following values for this ratio at different temperatures:—

Temperature.	$\frac{CO \times H_2O}{CO_2 \times H_2} = K.$	Temperature.	K.
786° C. (1,447° F.)	0·81	1,086° C. (1,987° F.)	1·95
886° C. (1,627° F.)	1·19	1,205° C. (2,201° F.)	2·10
986° C. (1,807° F.)	1·54	1,405° C. (2,561° F.)	2·49

This ratio rises with the temperature, and it is obvious that as the producer becomes hotter, change will take place towards the left-hand side of the reaction given by equation (6), tending to increase the percentage of CO. The addition of steam, lowering

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* *Zeitschrift für Physikalische Chemie*, 1903.

the temperature, will cause a change in the opposite direction. The oxidation of CO in this way causes an evolution of heat, and by raising the temperature gives an impulse tending to check the action. The conditions for stability are thus always in the direction of high temperature, and the consequent formation of CO.

Reaction (2) has now to be reconsidered. This also is a reversible reaction and depends on the temperature.

$$CO_2 + C \rightleftarrows 2CO \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

At a temperature of 1,790° F. Boudouard* showed that the percentages of CO and CO_2 in equilibrium with solid carbon under atmospheric pressure are 99 and 1 respectively; while at 1,497° F. they are 90 and 10, and at 1,090° F. they have become 20 and 80. Generally then, increase of temperature favours the formation of CO, giving richer gas and higher efficiency; while at lower temperatures a higher proportion of CO_2 is obtained. The steam supply to the producer has then an important effect, as it controls the temperature at which these reactions take place. It therefore determines the predominance of one side or the other of the reversible reactions, and so controls the composition and yield of gas, and thus, the efficiency of the process. If the steam supply is increased above a certain amount per lb. of carbon, the temperature and efficiency of the plant both fall. If, on the contrary, the supply is cut down too low, the temperature rises, gives bad working and increased heat-losses, and yields a poor gas. There is then clearly a certain proportion of air and steam that will give maximum efficiency, and it was one of the objects of these trials to find that point.

Description of Plant and Arrangements for Trials.—The entire plant was made in the workshops of the University of Birmingham, and is illustrated in Figs. 7, 9, and 10 (pages 354, 355, and 356). The producer, Fig. 7, consists of a wrought-iron shell, lined internally with a hollow cylinder of firebrick. The inside diameter of the

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* *Annales de Chimie et de Physique*, 1901.

FIG. 7.
Gas-Producer.

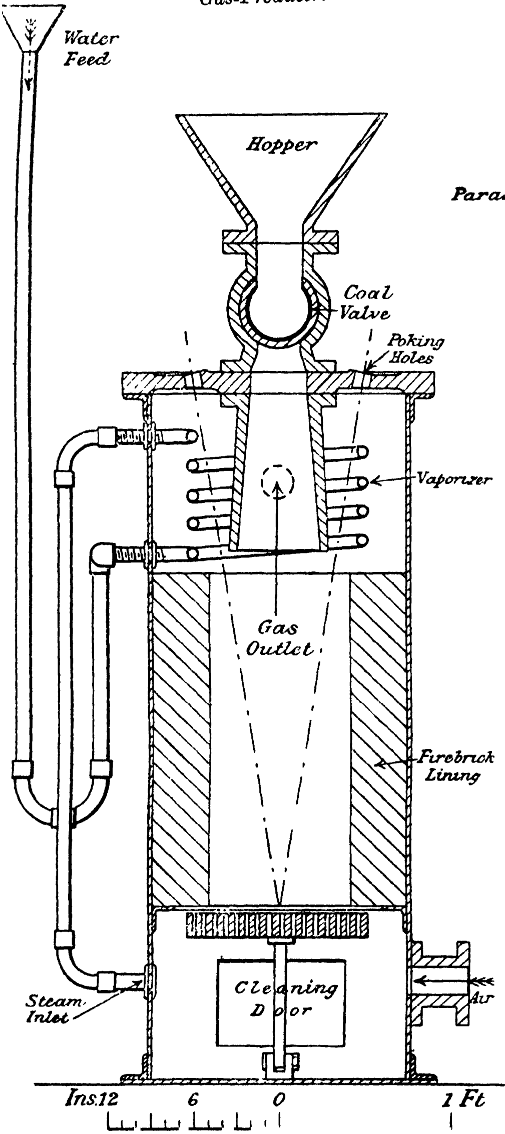
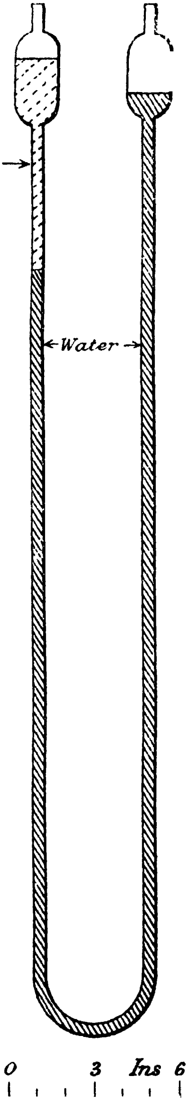


FIG. 8.
Differential Pressure-Gauge.



lining is 10 inches, and its height 25 inches. The joint between the bottom of the lining and the wrought-iron angle-ring that supports it, was carefully made with fireclay, and the space between lining and shell rammed with the same material. Notwithstanding these precautions, some of the air found its way up to the top of the producer through cracks in the lining, and produced a certain amount of CO_2 by combustion of CO. This accounts for the high percentage of CO_2 in the earlier trials, and partly for the low calorific value of the gas. The fuel level was kept as constant as possible by the distributing cone shown in Fig. 7. The conical coal-valve allows the coal to be charged into the producer without escape of gas or influx of air. The grate consists of a grid of wrought-iron bars, with spaces of ¼ inch between them, so that no coal can fall through without burning. The grid is hinged at one end, and supported by a movable bar at the other, so that it can be dropped at will, and the producer emptied through the cleaning door. The vaporizer consists of a coil surrounding the distributing cone in the top of the producer. The steam formed at the expense of the sensible heat of the gas passes out at the top of the coil, and is conducted by a lagged pipe to the ash-pit.

FIG. 9.—*Washer.*

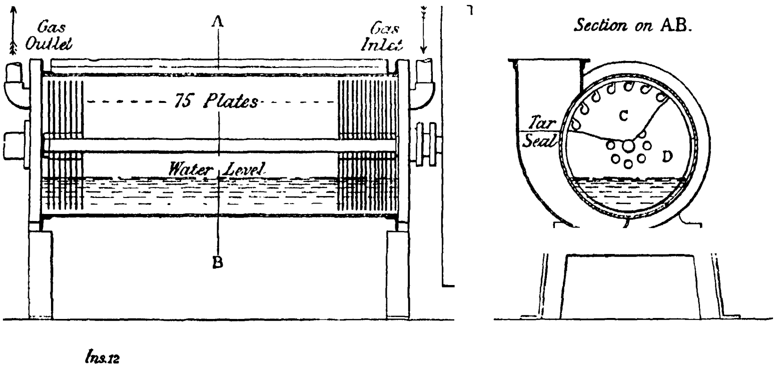
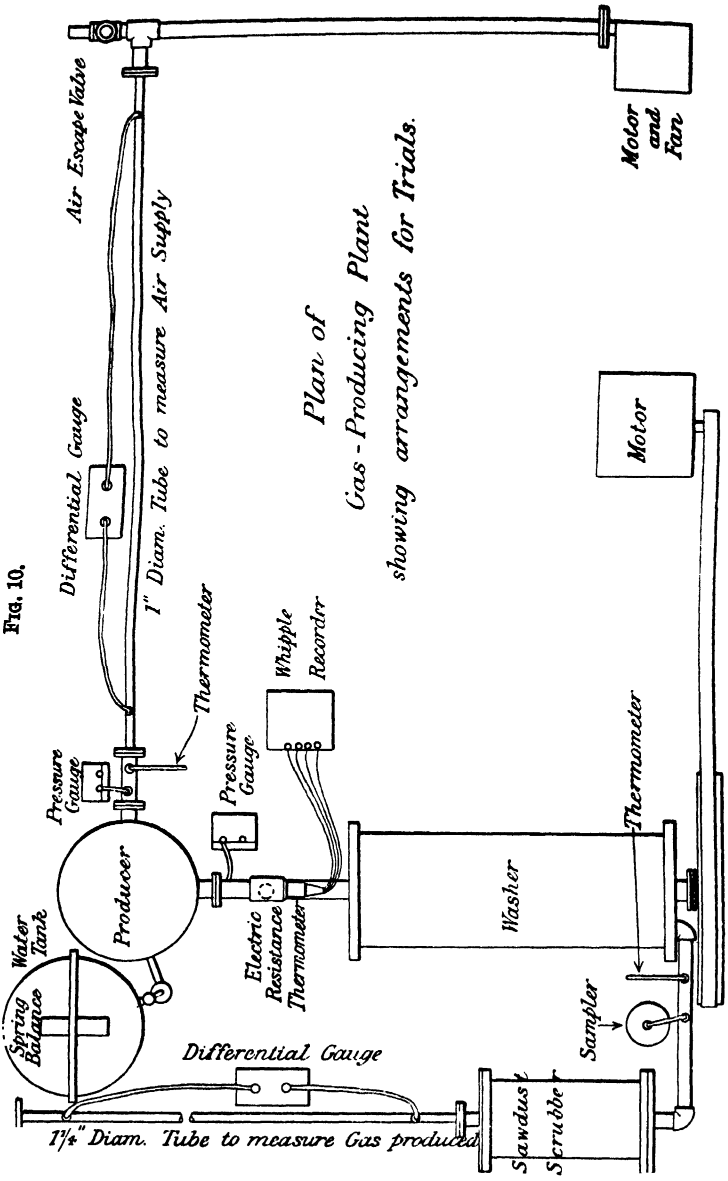


FIG. 10.



Plan of Gas-Producing Plant showing arrangements for Trials.

The washer, Fig. 9, is of novel construction. It consists of a cylindrical shell (18 inches diameter by 48 inches long), closed at the ends, and traversed by a shaft strung with thin discs 17 inches diameter. This shaft is rotated at 76 revolutions per minute. The discs are alternately pierced at the edge C, and the centre D, so that the gas is forced to pass in a zigzag direction from one end of the washer to the other. The washer is partly filled with water which is picked up by the small vanes on the discs marked C, and dashed intimately into contact with the gas. The large area of wetted surface thus presented to the gas makes this type of washer very efficient as a cooler.

The whole plant is shown in Fig. 10 as arranged for a trial. The air was supplied by a motor-driven fan, and its volume ascertained by measuring the drop in pressure down a narrow tube (9 feet long by 1 inch diameter). The differential gauge used for this purpose is shown in Fig. 8 (page 354). The large cross-sectional areas at the top give a large movement of the meniscus between the paraffin and water for a small difference in pressure. The movement of the meniscus was observed on a scale engraved in a mirror at the back of the gauge, and a calibration curve prepared by putting the tube in series with a standard gas-meter, and observing movements of the meniscus for various rates of gas supply. The same method was used for measuring the gas produced. The amount of air was adjusted to the required value by opening or closing the escape-valve in the air-pipe. The temperature and pressure of the air supply were also observed.

The water was fed into the vaporizer from a tank supported above the producer by a spring balance, from the readings of which the weight and regularity of the feed were ascertained. The temperature of the water-feed was taken at regular intervals.

The coal was weighed out in lots of 7 lb., a sample being taken at each weighing. Each trial was started with the producer full of coal, and the level in the hopper was noted. The weighed lots of coal were fed into the hopper in each case as soon as this level was reached, and at the end the surplus coal was taken out and weighed, so that the quantity used during the trial and the regularity of feed were accurately known. The pressure and temperature of the gas issuing from the producer were taken before delivery to the washer. The temperature of the gas leaving the washer was also observed, and samples of the gas were taken at this point. The volume of the issuing gas was observed in the same way as that of the air-supply, and its temperature on leaving the tube again taken. The gas-meter, which consisted of a tube (9 feet × $1\frac{1}{4}$ inch diameter) and differential gauge, could not be used in trials D and E, as the gauge was not available. In these trials, therefore, the volume of the gas was calculated from the equivalence of the nitrogen in the air supplied and gas produced. This probably does not involve any inaccuracy as, on referring to the other trials, it is found that the weight of nitrogen in air and gas is very nearly the same in each trial.

The reason for the adoption of so small a plant was to enable it to be tested in a short time. The actual duration of each trial was 4 hours, but the plant was run for some 3 or 4 hours in each case before any readings were taken, to enable the conditions to become steady before the trials were commenced. The steadiness of the conditions was judged from the constancy of temperature of the gas issuing from the producer. At the end of each trial an electric resistance thermometer was introduced into the producer through one of the poke holes, and the temperature of the producer taken at the grate, and at intervals of 3 inches upwards from the grate to the top of the producer.

All readings were taken at intervals of 15 minutes. The gas samples were taken over mercury at intervals of 30 minutes, and carefully analysed in the special apparatus described in the Third Report * to the Gas-Engine Research Committee by Professor F. W. Burstall. In this apparatus the pressure of the gas is taken after each absorption, and the volumes obtained in each case from these pressures. The volume of CO present was not obtained by absorption in cuprous chloride, but by explosion with air. The CO, hydrogen, and methane were all exploded together, and the

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* Proceedings, I.Mech.E., 1908, Part 1, page 5.

contraction, CO_2 formed, and oxygen used, measured in the usual way. This method gives three equations from which the respective volumes of the three constituents of the gas can be determined.* It was found in the preliminary experiments that, with weak mixtures, no explosion could be obtained. A small quantity of oxygen-hydrogen mixture obtained by the electrolysis of water was in these cases added before explosion to start the combustion. It was then found that the method worked successfully.

The calorific value of the coal was in each case ascertained by combustion in a Mahler bomb-calorimeter. The moisture and ash were also carefully estimated in each sample. The calorific value of the gas, heat lost in the washer, and water vapour entering the producer with the air were calculated from the observations. The calorific values used for this purpose were:—

CO . . . . = 340·9 B.Th.U. per cubic foot.
H_2 . . . . = 343 ,, ,, ,, ,,
CH_4 . . . . = 1,067 ,, ,, ,, ,,

The efficiency was in every case calculated from the calorific value of the raw coal, and the higher calorific value of the gas, and includes the heat required to vaporize the water-feed. The heat in the gas is also expressed as a percentage of the heat in the coal, for the sake of comparison.

Deductions: Decomposition of Steam.—The first noticeable point in these results is to be found in Fig. 11 (page 362). Here it is found that the percentage of hydrogen in the gas does not rise with increase of water fed into the producer, when the latter exceeds 0·75 lb. per lb. of coal. This corresponds, as seen from Fig. 12, to the decomposition of about 72 per cent. of the total

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* The equations are as follows:—

Let

$$CO = x,\ H_2 = y, \text{ and } CH_4 = z.$$

Then

$$\tfrac{1}{2}x + \tfrac{1}{2}y + 2z = \text{Oxygen used.}$$
$$\tfrac{1}{2}x + \tfrac{3}{2}y + 2z = \text{Contraction.}$$
$$x + z = CO_2 \text{ formed.}$$

TABLE OF RESULTS.

(Continued on next page.)

Trial.	A	B	C	D	E	F	G
Duration . hours	4	4	4	3·67	4·25	4	4·083
Coal supply . . lb.	59·8	62	60·25	57	63	62	63
,, ,, lb. per hour	14·95	15·5	15·06	15·55	14·83	15·5	15·4
Calorific value of coal B.Th.U. per lb.	14,250	14,300	14,250	14,950	14,500	14,200	14,600
Heat per hour in coal B.Th.U.	213,000	222,000	214,500	232,000	215,000	220,000	225,000
Moisture per cent. by wt.	3·97	3·58	4·29	2·55	3·4	3·52	3·04
Ash . ,, ,, ,,	3·41	3·26	3·57	2·2	3·06	3·33	2·87
Air supply at 32° F. and 14·7 lb. per sq. in. cu. ft. per hour	794	778	750	863	798	774	733
Temperature . . °F.	56·4	60	49	50	45	50	49
Air . lb. per hour	64·1	62·8	60·5	69·6	64·4	62·4	59·2
Nitrogen ,, ,, ,,	49·3	48·3	46·6	53·6	49·6	48·0	45·6
Oxygen . ,, ,, ,,	14·8	14·5	13·9	16·0	14·8	14·4	13·6
Air per lb. coal cu. ft.	53·1	50·2	49·9	55·5	53·8	49·9	47·5
Water in air lb. per hour	0·24	0·413	0·385	0·316	0·251	0·263	0·298
Water-feed lb. per hour	—	3·175	5·95	10·95	10·4	14·375	17·25
Temperature . . °F.	—	52	46	34	32	49	35
Total water to producer lb. per hour	0·24	3·588	6·335	11·266	10·65	14·64	17·55
Water per lb. coal . lb.	0·016	0·232	0·421	0·724	0·718	0·945	1·14
$\frac{\text{Wt. water per hour}}{\text{Wt. air per hour}}$.	0·0037	0·0572	0·1047	0·1617	0·1655	0·235	0·297
$\frac{\text{Wt. oxygen from water}}{\text{Wt. oxygen from air}}$.	0·0144	0·220	0·405	0·625	0·642	0·904	1·145
Gas at 32° F. and 14·7 lb. per sq. in. cu. ft. per hour	970	1040	1050	1238	1165	1095	998
Ditto cu. ft. per lb. coal	65	67·2	69·8	79·6	78·6	70·7	64·7
Composition by volume N_2 per cent.	63·3	59·4	56·7	55·2	54·2	55·6	58·7
Ditto. CO ,, ,,	28·5	26·5	24·5	23·0	23·5	20·7	20·0
Ditto. CO_2 ,, ,,	7·2	7·5	7·7	8·0	8·5	9·7	8·8
Ditto. H_2 ,, ,,	0·5	6·1	10·5	13·3	13·5	13·3	11·5
Ditto. CH_4 ,, ,,	0·5	0·5	0·6	0·5	0·3	0·7	1·0
Total combustibles . .	29·5	33·1	35·6	36·8	37·3	34·7	32·5
Nitrogen lb. per hour	48·9	48·5	46·6	53·5	49·5	47·8	46·0
Hydrogen ,, ,, ,,	0·027	0·355	0·617	0·925	0·88	0·817	0·645
Water decomposed lb. per hour	0·24	3·20	5·55	8·33	7·92	7·35	5·8

TABLE OF RESULTS.

(Continued from previous page.)

Trial.	A	B	C	D	E	F	G
Water-feed decomposed per cent.	100	89·3	87·8	74	74·4	50·2	38
Water decomposed per lb. coal . . . lb.	0·016	0·208	0·369	0·536	0·535	0·474	0·376
Calorific value of gas B.Th.U. per cu. feet	104·3	116·8	125·9	129·5	129·6	123·9	118·3
Total heat in gas per hour B.Th.U.	101,300	122,000	132,100	160,500	151,000	135,800	118,000
$\frac{\text{Heat in gas}}{\text{Heat in coal}}$ e_1 per cent.	47·6	55·0	61·7	69·2	70·2	61·8	52·5
Heat to vaporize water-feed per hour B.Th.U.	—	4040	7160	12,870	12,200	16,530	20,050
Ditto . . per cent.	—	1·82	3·34	5·55	5·68	7·52	8·92
Thermal efficiency e_2 = $\left(\frac{\text{Heat in gas + heat to vaporize water-feed}}{\text{Heat in coal}}\right)$ per cent.	47·6	56·82	65·04	74·75	75·88	69·32	61·42
Temperature of gas leaving producer . °F.	750	665	600	550	545	550	554
Temperature of gas leaving washer . . °F.	121	120	129	116	120	120	120
Heat lost in washer per hour . . B.Th.U.	20,950	20,030	18,270	19,530	19,020	18,170	16,720
Heat in coal per hour per cent.	9·84	9·03	8·52	8·43	8·85	8·27	7·45
Heat lost in washer including sensible and latent heat of water vapour . . .	—	—	19,396	20,140	19,570	19,880	24,810
$\frac{\text{Heat lost in washer}}{\text{Heat in coal}}$ per cent.	—	—	9·03	8·67	9·1	9·02	11·0

Fig. 11.—*Gases. Comparison with 1906 Tests.*

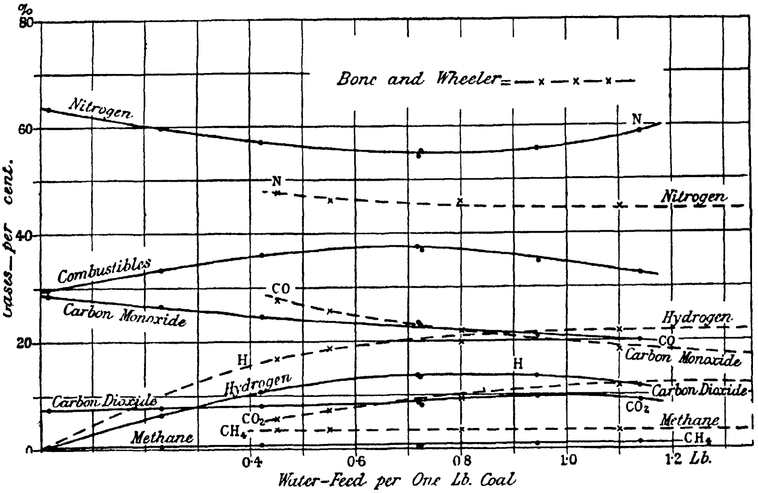
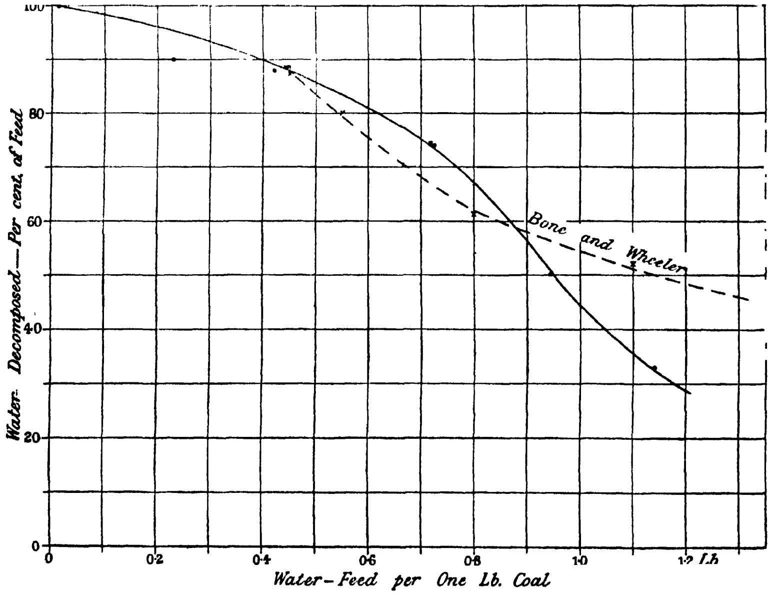


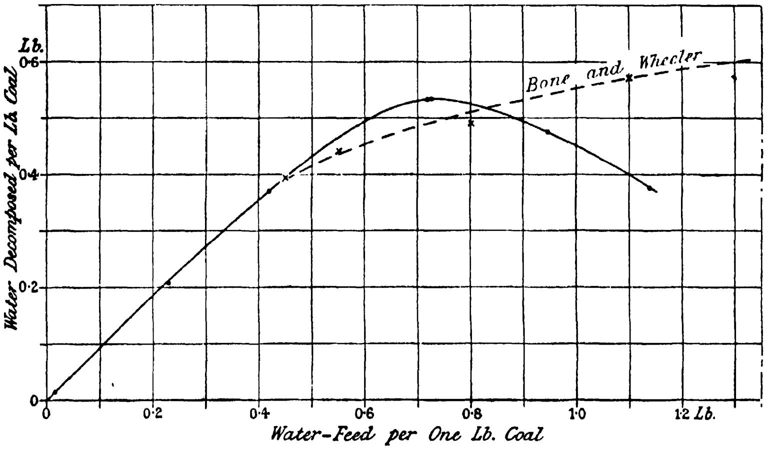
Fig. 12.—*Water decomposed. Comparison with 1906 Tests.*



weight of water fed in the producer. This result is very important, as it shows that the maximum amount of steam that can be decomposed by anthracite at a temperature of about 1,832° F. is about 0·535 lb. per lb. of coal, Fig. 13. Referring to the curve of Messrs. Bone and Wheeler (shown dotted on Fig. 13), it appears from the flattening of the curve that this maximum is in the neighbourhood of 0·625 lb. of water per lb. of coal, for large producers working on bituminous coal. It follows that there can be no advantage, but only loss, in pushing up the steam supply beyond 1½ lb. of steam per lb. of coal for large producers and about ¾ lb. of steam per lb. of coal for small ones. If these values are greatly exceeded, the increased supply of steam merely takes heat from the producer and loses it in the washer. The presence of such excess of steam has, of course, an effect in keeping down the temperature of the producer, and this is advantageous when it is desired to recover ammonia from the gas, but in all other cases such excess is harmful, as it has been repeatedly shown that large quantities of steam are not necessary for the prevention of clinkering. The low percentage of hydrogen in the gas is due to

FIG. 13.

Water decomposed per Lb. Coal. Comparison with 1906 *Tests.*

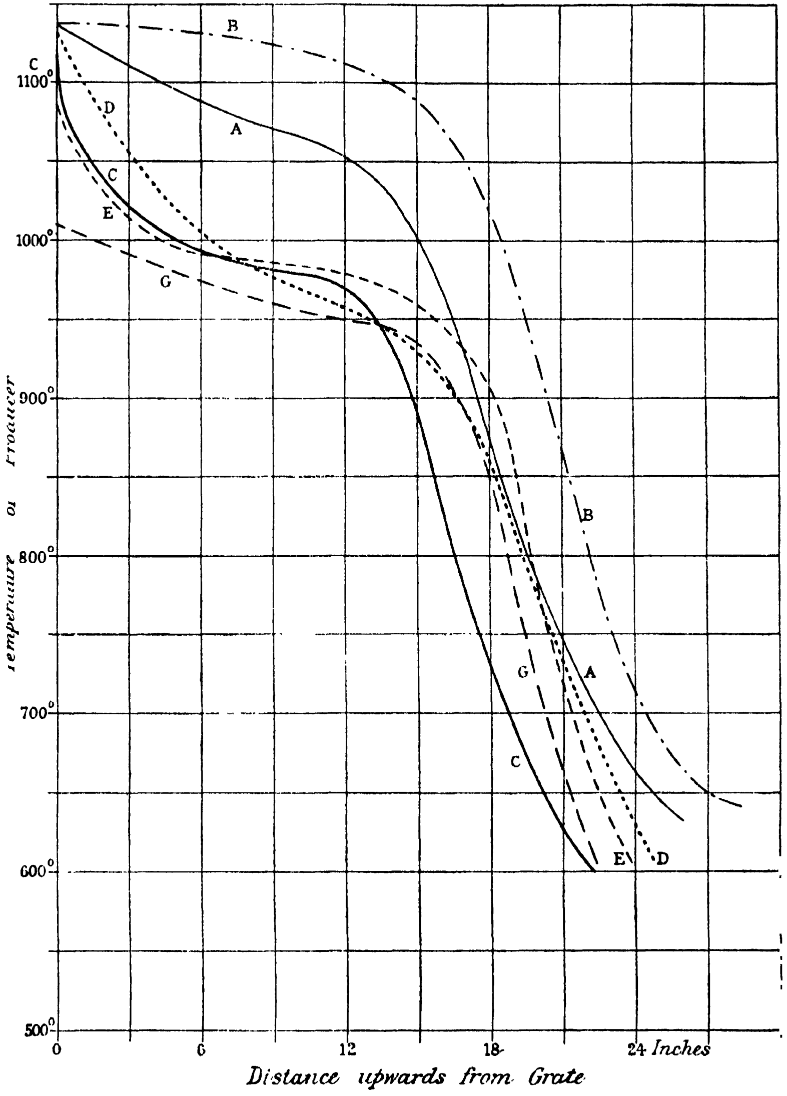


the large proportion of air which had to be used to keep the vaporizer at a sufficiently high temperature to supply the necessary amount of steam, owing to the inefficiency of the internal steam-coil. This resulted in a high ratio of air to steam, and the consequent presence of a large quantity of nitrogen in the gas.

The Combustion of Carbon.—The most significant result of these trials is, that the percentage of CO_2 remains practically constant, in spite of the increasing feed of steam to the fire. The high content of CO_2 in the trials where little or no steam is supplied is due, as has been seen, to a leakage of air. Eliminating the 7 per cent. of CO_2 in the first trial as due to this cause, it is found that the maximum rise during the whole of the trials is merely about 2·5 per cent. It would naturally be expected that the increased supply of steam would diminish the temperature inside the producer, and result in the production of increasing quantities of CO_2 from reactions (5), (6), and (7). This is admirably shown in the trials of Messrs. Bone and Wheeler, where the CO_2 (shown dotted, Fig. 11) is seen to rise from 5·25 per cent. at 0·45 lb. water per lb. coal to 13·25 per cent. at 1·55 lb. water per lb. coal. Why does not the same rise occur in the author's experiments? It seems at first sight that these experiments contradict the theory laid down at the beginning of this Paper—a theory supported by experimental evidence in the tests of Messrs. Bone and Wheeler. The contradiction, however, is only apparent. At the end of each trial, as has already been seen, the temperature of the fuel in the producer was taken at equidistant levels from the grate to the top of the fuel bed. Although the temperature curves thus obtained, Fig. 14, are, as might be expected, somewhat erratic, yet there is one characteristic which is common to all. The temperature keeps fairly constant at about 1,832° F. (1,000° C.) for a distance of about 18 inches upwards from the grate, and then falls rapidly to about 1,112° F. (600° C.) in the next 6 inches or so. In the first 18 inches, then, the combustion of the carbon and oxygen is obviously taking place, and all the heat is developed. After this point, the steam begins to affect the temperature, and causes it to fall with extreme rapidity.

FIG. 14.

Temperature of the Fuel at various distances above the Grate.



Now, as has been seen, at a temperature of 1,832° F. (1,000° C.) no CO_2 can exist in contact with excess of carbon. The large excess of oxygen at the grate causes the carbon to burn to CO_2 * with the evolution of large quantities of heat, and the maintenance of a high temperature. The excess air burns higher up in the producer, and so maintains the temperature, but as we get farther away from the grate, the reduction of CO_2 to CO, and the endothermic steam reactions begin to have the predominating effect on the temperature. The first 18 inches, then, may be termed the zone of active combustion, where owing to the high temperature the gases produced are almost entirely CO and hydrogen. There is above this about 6 or 7 inches of fuel bed in which the temperature is rapidly falling. This would have its due effect in re-forming the CO_2 by reactions (5), (6), and (7), if it were not so thin. The shallowness of this comparatively cold layer of fuel does not allow sufficient time for these reactions to affect seriously the composition of the gas and the efficiency of the producer.

In a deep fuel bed, say 7 feet deep, as in the producer used by Messrs. Bone and Wheeler, the first 2 feet or so will form the zone of active combustion, but the thickness of the bed of cooler fuel above will much more seriously affect the composition of the gas. In fact, the amount of CO_2 in the resulting gas will simply be the result of the reactions corresponding to the mean temperature of the belt above the zone of active combustion, and to the time during which the gases are in contact with the coal in that belt—that is, it will depend upon the depth of fuel in the producer, beyond the zone of active combustion, and the velocity of the gas. This shows that in producers which have a shallow fuel-bed, provided there is no leakage, there need not be more than 2 per cent. or 3 per cent. of CO_2 present in the gas. If more than this quantity is present, it is due either to leakage or to the use of too great a quantity of air for the size of the producer. In the latter

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* Mr. Thwaite found in a producer working with air alone, that at the grate only 2 per cent. of CO was present, while at 15 feet above there was 28 per cent. Journal, Iron and Steel Institute, No. I, 1907, page 165.

case, the velocity of air through the fuel is high, and some of the CO_2 formed by combustion in the active zone escapes reduction to CO. The depth of the fuel bed should therefore be cut down to the lowest value consistent with practical working. In large producers a deep fuel-bed is necessary, as the larger sizes of coal used in them do not pack as well as the smaller pieces, and the distribution of air across the section of the fuel-mass is apt to be irregular. In such cases it might even pay to have a secondary air-supply admitted some distance above the grate. This would have the effect of introducing another zone of active combustion, in which the heat evolved by the combustion of the secondary air to form carbon monoxide would be available for reducing the CO_2 coming from the grate, according to the reaction expressed in equation (7). The depth of the cool layer of fuel above the active combustion zone would thus be reduced, and the re-formation of CO_2 according to the reaction expressed by equation (6) would be greatly diminished.

Calorific Value of Gas.—The calorific value of the gas is very low throughout, Fig. 15 (page 368). This is partly due to the low percentage of hydrogen which is the outcome of the high ratio of air to steam. The nature of the fuel also is accountable for the very low percentage of CH_4 which has a great influence on the calorific value. It is noticeable that the percentage of combustibles in the gas regularly increases until 0·7 lb. water per lb. of coal is reached, and then decreases again. The calorific value also reaches a maximum about this point.

Efficiency.—In this Paper, the efficiency of the producer is taken as the ratio between the heat generated which does useful work outside the producer itself, and the total heat in the coal used during the same period.

It will be seen from Fig. 16 that the maximum yield of gas occurs at a water-feed of about 0·75 lb. per lb. of coal. This is about the point where the maximum percentage of hydrogen is obtained, and where the calorific value of the gas is highest. It

Fig. 15.—*Calorific Value.*

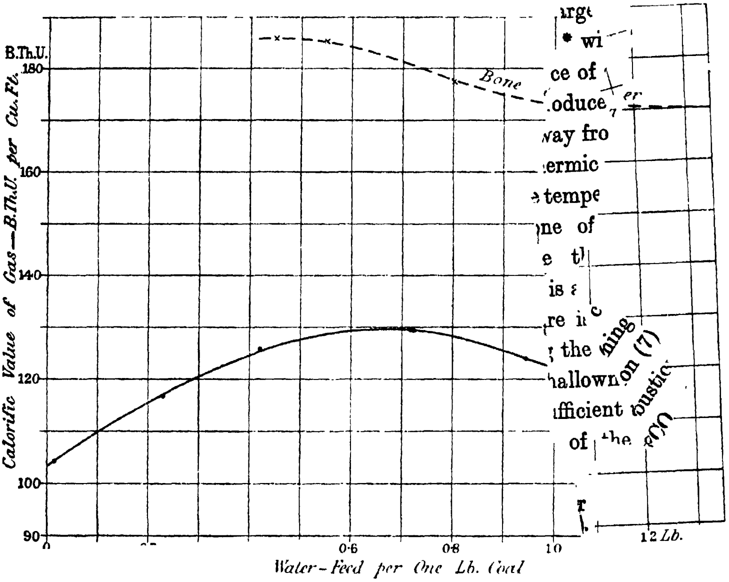


Fig. 16.—*Gas Produced.*

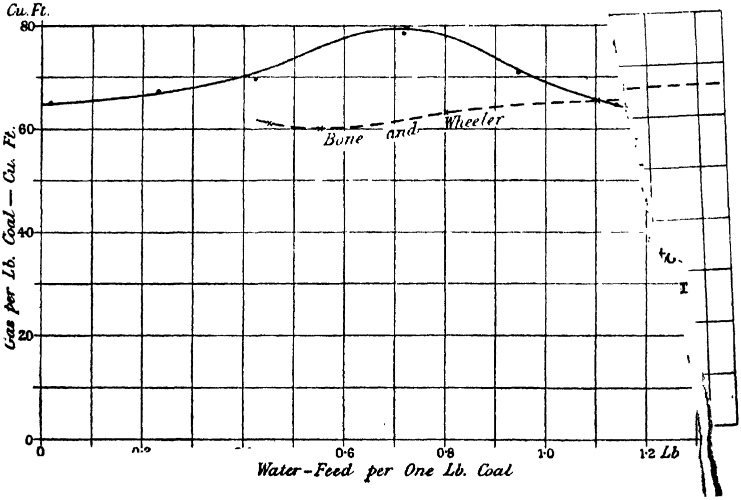


FIG. 17.—*Thermal Efficiency.*

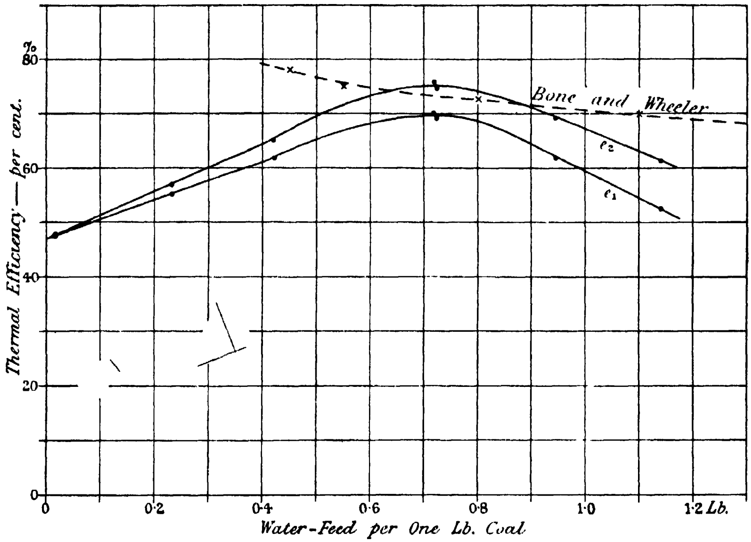
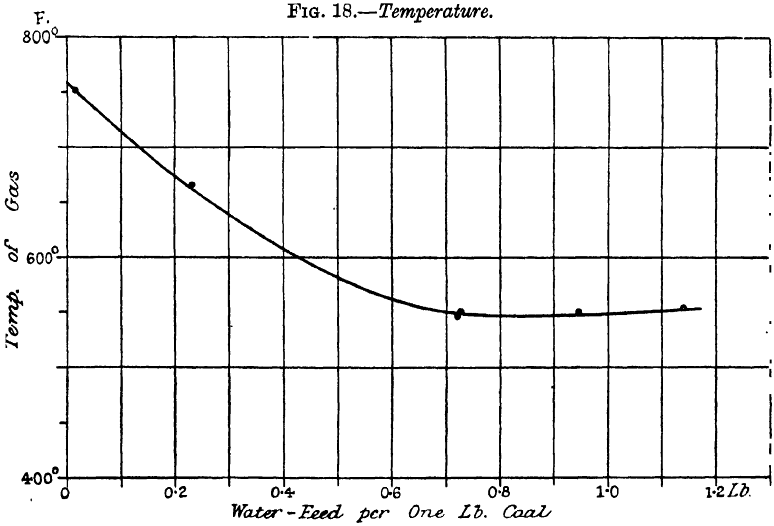


FIG. 18.—*Temperature.*



follows, therefore, that the efficiency of the producer reaches its maximum at this point. The lower curve e_1, Fig 17, gives the percentage ratio of the heat per hour in the gas produced to that in the coal used. The higher, e_2, includes the percentage of heat necessary to vaporize the water supply. The latter represents heat that would otherwise be lost in the washer, and as it is taken from the producer it should be credited to that source of supply. The higher value, e_2, is therefore the true efficiency of the producer. Messrs. Bone and Wheeler at the end of their Paper say, "In our opinion, the maximum of advantage derivable from the use of steam, depends to some extent on the thickness of the fuel bed." In the conditions obtaining in their trials, the maximum efficiency was probably attained between 0·4 and 0·5 lb. of water-feed per lb. of coal. The shallower fuel-bed existing in the producer tested by the author, with its consequent high mean temperature, resulted in the advantageous use of a higher proportion of steam than could be economically used in a producer having a deeper fuel-bed.

The temperature of the gas leaving the producer is shown in Fig. 18. The highest temperature was attained in trial A (in which no water was fed into the vaporizer), being about 750° F. A steady fall was maintained with the increase in water-feed until trial D was reached, when the temperature was about 550° F. After this, the temperature remained fairly constant.

The washer loss is almost constant from trials A to D, the fall being simply due to the drop in temperature of the gas. After this point, however, it rises rapidly, owing to the sensible and latent heat carried over by the surplus steam. The dotted line, Fig. 19, shows the heat carried away by the gas alone. The sharp upward slope of the latter end of the curve shows the necessity for regeneration where large quantities of steam are used.

In Fig. 20 the efficiency e_2 is plotted against the ratio $\frac{\text{oxygen in steam}}{\text{oxygen in air}}$. It shows that the efficiency is proportional to this ratio up to a certain point (0·65), after which it bends sharply and becomes inversely proportional to that ratio. For the sake of

FIG. 19.
Washer Loss.

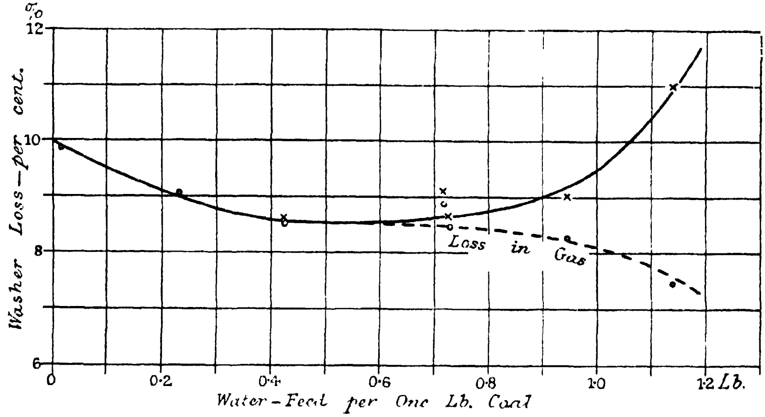
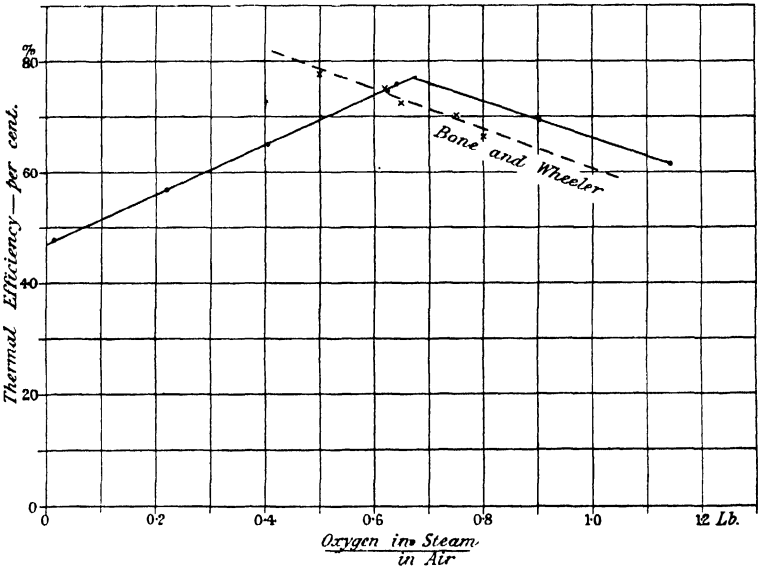


FIG. 20.
Thermal Efficiency.



SALAR JUNG BAHADUR

comparison, the results of Messrs. Bone and Wheeler are plotted on the same diagram. It will be seen that the down grades of these curves are almost exactly parallel. It appears from this, that the increased supply of steam beyond the point of maximum efficiency causes a decrease in efficiency proportional to the ratio $\frac{\text{in steam}}{\text{oxygen in air}}$. This decrease, in the case of these two producers, is the same for equal rises in the value of the ratio. Whether this also holds for other producers can only be determined by further investigation, but the fact that it is the same for two producers that are so different as these are appears to be significant.

The author desires to express his thanks to the authorities and staff of the University of Birmingham for their kindness and assistance during the prosecution of this research.

The Paper is illustrated by 14 Figs. in the letterpress.

[*The Discussion on this Paper was combined with that on the Paper by* Mr. J. Emerson Dowson, *and commences on the opposite page.*]

Discussion.

The PRESIDENT, in moving the thanks of the Institution to the authors of the Papers, said that Mr. Dowson was a past master on the question of Gas-Producers; he supposed there was no man living who had done more to popularize gas-producers in this country, or to increase their efficiency. Mr. Dowson's Paper was a very practical one, and would form a most valuable contribution to the Proceedings of the Institution.

Mr. Allcut's Paper was of a different character, and was a most interesting series of experiments, producing certain results which had been put before the Members.

The Vote of Thanks was carried with acclamation.

Captain H. RIALL SANKEY, Member of Council, said Mr. Dowson's Paper was a most admirable historical résumé of what had been done with regard to gas-producers. Mr. Dowson had referred in many places to the various conditions which influenced the thermal efficiency of the producer, but as far as he (Capt. Sankey) could make out, Mr. Dowson did not state what that efficiency was. He would ask him to give the thermal efficiency of, for example, a suction producer when the engine was working at full load, at three-quarters load, at half load, and at a quarter load; such information would be extremely valuable.

On Table 1 (page 333) the calorific value was given on the higher scale. He (Captain Sankey) thought this was to be regretted, because the Institution of Civil Engineers had accepted the recommendation of their Committee on "Standards of Thermal Efficiency of Internal Combustion Engines" that the calorific value should be taken on the lower scale. This rule was based on the simple reason that the latent heat in the steam could not in any way be used by the gas-engine, and ought not therefore to be taken into account. By putting the calorific value on the higher scale, the author made a difference in the gas of a considerable amount. In gases containing much hydrogen and methane the difference in the two

(Captain H. Riall Sankey.)

values was considerable. For example, in the gas given in Table 1 (col. 2) the difference would be, as a guess,* about 15 B.Th.U.

Mr. Dowson, interrupting, said it would make about 12 B.Th.U. difference.

Captain Sankey, continuing, said, in various parts of the Paper the gas was spoken of as being of a greater, or of a lower, calorific power. On page 335, for instance, the author said, "The calorific power of the gas will be lower." That might be misconstrued, and it might be thought that a gas of greater power was better than one of lower power when used in a gas-engine. That was not so. Taking an extreme case where the gas was produced in a blast-furnace, the calorific value was about 100 B.Th.U., and yet the thermal efficiency of a gas-engine using such gas was quite as good as that of others. Nor was the power obtainable from a given cylinder greatly affected, because when the proper amount of air was added for exploding the gas, the calorific value per cubic foot of the explosive mixture was nearly the same whatever the calorific value of the gas. Town gas, for example, had a calorific value of about 550 B.Th.U., and a proper amount of air to add was, say, 7 volumes, which gave calorific value per cubic foot of the explosive mixture of about 70. A suction gas of 140 B.Th.U. calorific value required about one volume of air, and the calorific value of the explosive mixture was again 70 B.Th.U. per cubic foot. Therefore, from the gas-engine point of view, it could not be said that a gas was better or worse because it had a greater or a lower calorific power.

The most important matter in the Paper, to his mind, was contained in pages 342 to 344, where Mr. Dowson described his new producer for working with bituminous coal. From the results given, Mr. Dowson seemed to have hit upon the right thing at last. Everybody had been attempting for many years to make a producer that would work with bituminous coal, and in such a

* By calculation the difference is found to be 10·8 B.Th.U.

manner that no tar could get into the engine. He remembered years ago seeing such a producer which worked beautifully on paper, but in actual practice it was found the gas would not follow the arrows which directed its course on the drawing. He hoped that would not be the case with Mr. Dowson's producer.

Mr. MICHAEL LONGRIDGE, Vice-President, said it seemed to him a very fortunate chance which had enabled the Council to bring before the members two Papers on the same subject, written from entirely different points of view. One Paper was by a maker of producers, the other by a student who was working at a University and experimenting to discover the laws under which producers should be worked. One was the Paper of a practical, the other of a theoretical, man. It had been customary in past years, and the custom was not entirely obsolete even now, to decry the theoretical man, but he thought the two Papers that night showed how foolish the custom was. In Mr. Allcut's Paper, which he did not propose to discuss at any length, certain facts were given of the utmost commercial importance, facts which would enable the engineer, if he properly grasped them, to understand some of the difficulties which occurred in the working of gas-producers, why those difficulties occurred, and how to get over them. The other Paper gave no such definite information. It told engineers that it was essential there should be a sufficiency of steam supplied to the burning fuel. What was a sufficiency of steam? Mr. Allcut said that in a small producer a sufficiency of steam was about 0·7 lb. per lb. of coal, and in a large producer about 0·5 lb. Mr. Dowson said that there should be a zone of sufficiently high temperature to make good gas. What was a sufficiently high temperature? Mr. Allcut said it was 1,832° F., and further pointed out the influence which the depth of the zone of high temperature and of the superincumbent zone of cool coal had upon the composition of the gas. Mr. Allcut explained how with a small superincumbent weight of coal the CO which was produced in the hot zone had not time to be oxidized to CO_2, whereas with the deeper cool zone the CO which was produced in the hot zone became oxidized, and a larger proportion of CO_2 was

(Mr. Michael Longridge.)

obtained in the gas. This was valuable information, which engineers could make practical use of. But while he laid stress upon the value of Mr. Allcut's Paper, he did not wish to decry Mr. Dowson's. The latter was a good descriptive Paper, and offered more opportunity for a good discussion than Mr. Allcut's. It purported to deal with the construction and working of producers and was welcome because it gave him the opportunity of mentioning one or two matters which seemed to need consideration.

The first was corrosion, especially corrosion of scrubbers. Nearly all scrubbers suffered more or less, and where coke was used in the generator, corrosion was often very rapid, in some cases perforating the plates in three or four years. The lower and hotter parts suffered most, and he thought something ought to be done to prevent the mischief. He could not see why scrubbers could not be made of pot, but if they could not, the lower parts at least should be made of cast-iron, especially if coke were the fuel to be used. He believed one firm was now using this material.

Another part which required attention was the vaporizer. Some were made of wrought-iron or steel, some of cast-iron, some were put inside the furnace, some outside. Few, if any, were provided with proper facilities for cleaning. Many of them gave trouble; wrought-iron tubes inside the furnace became choked with deposit and burnt through, and cast-iron in a similar position cracked. Wrought-iron heated by the gas from the producer corroded rapidly; cast-iron gas-tubes with jackets cast on them for heating the air and generating steam cracked by unequal expansion. For vaporizers containing steam and water only, wrought-iron or steel was probably the best material, especially if placed inside the furnace, but when the vaporizer was used for heating air as well as generating steam, cast-iron lasted better. In either case, facilities for cleaning and provision for unequal expansion of parts were essential.

Another matter not sufficiently appreciated by some makers of producers was the risk of explosion. Most plants were more or less like the diagram, Fig. 21, consisting of a generator *a*, a pipe *b c* leading to a scrubber with a chimney-pipe *b d*; a scrubber *e* and an expansion box *f* with an escape-pipe *g*. What he would like to see was:—

(1) A two-way cock at *b* which would place the generator in communication with the chimney *d* or with the scrubber *e*, but would prevent communication between the scrubber and the chimney.

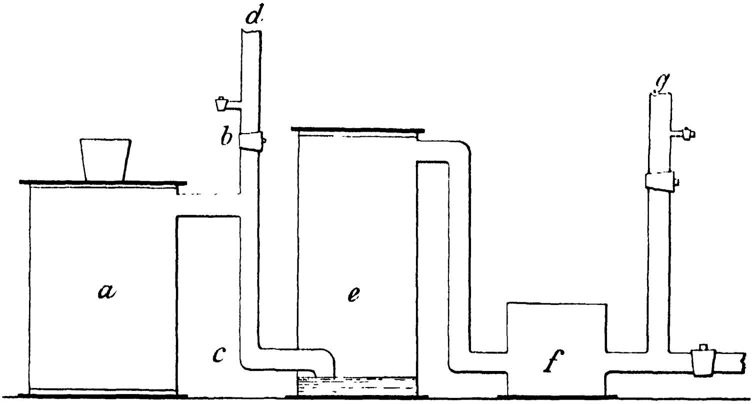
(2) A water-seal at the bottom of the scrubber.

(3) An automatic atmosphere-valve in the escape-pipe *g*.

(4) Test-cocks with wire-gauze flame-arresters in the chimney *d* and escape-pipe *g*.

(5) Water-seals to all drains.

Fig. 21.



With these appliances he thought a gas-engine could be started on suction-gas without risk of explosion, whether it were started on the gas sealed up in the producer overnight or whether the gas left in the scrubber and expansion-box overnight were blown out and replaced by fresh gas at each starting of the engine.

In the first case, the two-way cock at *b* would be set open to generator and atmosphere when the engine stopped, and the gas in the scrubber and expansion-box would be bottled between the two cocks *b* and *g*.

Before starting the engine, the fire would be blown by the fan till the test-cock in *b d* showed good gas. The two-way cock *b* would then be opened to generator and scrubber and the cock *g*

(Mr. Michael Longridge.)

opened; blowing would be continued and the gas tested at *g*. If the gas were good, the engine would be started, but if the gas in the scrubber and receiver had been vitiated, it would be blown out first.

With these precautions he thought there would be fewer explosions than there were at present. Without them it was possible, particularly where there was no water-seal at the bottom of the scrubber, for air to get into it and into the expansion-box if the cocks *b* and *g* were inadvertently left open when the engine was standing.

He had hoped that Mr. Dowson's Paper would give some information as to the cross-sectional area and depth of fuel required for various kinds of fuel and various intensities of draught. He had never been able to obtain information on these points, and had come to the conclusion that producers were not designed with reference to these considerations but were merely turned out as cylindrical chambers to hold fuel, irrespective of the quality of the fuel or of the quantities of air to be passed through them.

He thought it would lead to greater efficiency and to the comfort of those who had to work producers, if some theory were established by experiments as to area and height, and perhaps as to shape as well.

Mr. T. W. Stainer Hutchins remarked that whilst all the members must thank both the authors for their Papers, especial thanks should be given to Mr. Dowson, as, but for his work on suction producers, there would have been fewer installed, and consequently fewer opportunities for theoretical calculations and tests, and he thought that all engineers agreed that Mr. Dowson had helped considerably in the perfecting of this type of producer.

Dealing with Mr. Allcut's Paper. If the air had been mixed with steam instead of being brought in on the opposite side of the producer, different results would have been obtained, that is, there would have been a higher rate of water consumption per lb. of fuel gasified. Furthermore, if the air had been heated by means of an air-belt round the producer, an increase in water consumption per lb. of fuel gasified would again be obtained, so that, whilst it had to be acknowledged that the amount of water stated was the maximum that could be gasified in Mr. Allcut's experimental producer, in a commercial producer the maximum would be much higher.

With regard to corrosion in producers, he was afraid it was mostly caused by the buyer, who accepted the cheapest tender, and expected the best plant. It was no use a firm putting improvements in, if prices were going to be cut.

With reference to Mr. Dowson's Paper, he would like to know if Mr. Dowson had run his double-blast producer on varying loads, and if he had had trouble by the blocking up of his vaporizer. When volatile matter passed through the heat zone, a sort of graphite resulted which was very difficult to remove. The coke-washer was practically of no use. The most effective means for removing it were large sawdust-scrubbers, but these would have to be very large to give sufficient area. Even then graphite found its way into the engine, and meeting with the lubricating oil formed a sticky matter which interfered with the working of the engine-valves, etc.

As mentioned by Captain Sankey (page 374), these producers had been tried from time to time without success. If Mr. Dowson had obtained success on this producer he had achieved something very good. In the producer Mr. Dowson mentioned, he was running under favourable conditions, as Nottingham slack was considered an ideal fuel for bituminous plants.

With regard to the question of standby losses, which was very important to those interested in power plants, in some tests taken from two to three years ago on a 2,000 h.p. Mond producer, the standby loss was 14 lb. per hour of bituminous fuel. He thought the period of test was carried over a month, with 12 hours standby.

With regard to the question of steam consumption, this varied considerably with the type of plant, being from 0·5 lb. to 2½ lb. per lb. of fuel gasified. Whilst the former figure was very often taken and worked upon for small plants running on anthracite, the latter was taken for producer-gas plants arranged for the recovery of ammonia. A considerable portion of the steam in the latter case

(Mr. T. W. Stainer Hutchins.)

was recovered or raised within the plant itself. This large amount of steam was used with the object of keeping down the temperature in the producer and so getting the maximum yield of sulphate of ammonia. In small bituminous plants non-recovery, such as the "Mond" type, the blast temperature was usually run at 60° to 70° C., which meant about 1 lb. of water per pound of coal. A certain amount of condensation took place, but it therefore did not follow that the amount of moisture or steam going in with the gas passed through the fuel in the producer.

With regard to the remarks which had been made about producer manufacturers, the same remarks might apply to a man who had a little backyard, a hammer, a few rivets, and a few pieces of iron, and who started to make a producer. He did not think the remarks about not knowing the amount of water or the depth of fuel, or the area of the producer being more or less a rule of thumb, applied to the producer-plant specialists. Such things were well known to the producer makers, and had been for many years. The depth of fuel and the diameters varied with the quality, and the size: that was one of the simplest problems connected with producers.

Mr. Longridge remarked he did not say the makers did not know, but that he personally had not been able to ascertain those facts. He believed the makers did know them.

Mr. F. Howard Livens thanked the authors, each in his way, for having contributed so much to the knowledge of the subject. He would like Mr. Dowson to give some indication as to whether or not there was any difficulty in regulating the height of the zone of combustion, as there was air going down from the upper part, and steam and air coming up from the lower part. He wished to say a few words as to how the producers were worked. The members had heard about the manufacturer, and the principles of action, but, if they thought for a moment of the people who worked the producers, he was sure they would see that there were many difficulties in the way of a complete solution of the problem.

He knew of instances where the least skilled man who could be found was put on to work the producer, and the employment of that man was supposed to be economical; sometimes indeed, if he had had nothing to do with steam practice previously, it was an advantage! It was a fact that gas plants and gas-engines were worked by men who had absolutely no engineering knowledge whatever, but at the same time he must say that on the whole they were worked very successfully. It could not therefore be expected under those conditions that one would always get the exact percentage of water necessary to work the producer most economically. It must vary more or less, and he, for one, could not see how an apparatus could possibly be arranged which would be elastic enough always to feed the water to the producer in the right quantities for no-load and for full-load. The truth of the matter was that the apparatus was both successful and economical, but engineers had to be content that it should often work not under its best conditions.

He had been very much interested in Mr. Longridge's remarks as to what happened in practice. There was no doubt whatever that makers had made the plates of their scrubbers much too thin; taking into account the low pressure conditions, they apparently had looked upon the casing as being in equilibrium, and that, therefore, there was no necessity for strength. The consequence was there was not thickness enough in the scrubbers produced by some manufacturers to withstand corrosion. With regard to the two-way valve which Mr. Longridge had asked for between the producer and the scrubber, he could assure that gentleman there were makers who regularly put that valve in; his own firm never sent out a producer without such a valve, so that the accident to which Mr. Longridge referred could not happen.

Mr. Allcut's Paper was particularly interesting on account of the very careful and painstaking way in which the results had been obtained. Personally, he would not have thought it possible on so small a producer to be very sure of the results, his own experience being that a small producer was very difficult to control. He would like to point out how almost universal the practice was

(Mr. F. Howard Livens.)

becoming of making gas-engines with throttle or quantity governing, instead of the old-fashioned "hit-and-miss." In this connection he thought we owed a good deal to the Continental practice, which, whilst responsible in the past for many extraordinary governing arrangements, had led to the development of designs which were very simple and efficient. The time had really come, in his opinion, to make all gas-engines on that principle. Referring to Mr. Longridge's remarks on the apparently haphazard dimensions of producers, he could mention one maker at least who, recognizing that correct proportions should be adopted, listed for the same engines, producers of three different capacities, according to the kind of fuel which had to be used.

Mr. W. A. TOOKEY said that, as the discussion so far had been more or less confined to questions relating to construction, he was glad of the opportunity afforded him to make some comments from the point of view of those engineers who were called upon to express opinions—sometimes commending, sometimes condemning—upon the working of gas-producers. He knew that in one or two instances there had been occasion to report unfavourably upon the working of gas-producers, but on the whole an extremely small proportion had been utterly condemned. Mr. Longridge had made some suggestions as to improvement of details, but some of the points he had mentioned were already features of up-to-date construction. Other suggestions were more or less in the nature of refinements, and however much they might be desirable it was a regrettable fact that as the general body of purchasers were not engineers, they apparently objected to pay 10 per cent. increase in price for 25 per cent. greater efficiency. Consequently, it was a little unfair to blame makers of gas-producers who had to compete very keenly in the open market in order to sell their goods. It was hard to criticize them for the omission of some appliance or detail which, although making for the improvement of the apparatus with regard to efficiency, was, after all, not of vital necessity.

Dealing with the Paper read by Mr. Dowson, the speaker said that engineers interested in the application of gas power owed a great deal to the author for the pioneer work he had carried on so successfully. He thought that Mr. Dowson could well be called the father of the gas-producer for power purposes, and also the step-father of the gas-engine, for the latter had thrived very considerably since its birth, both in regard to size and estate, as a result of the cheap food that Mr. Dowson had provided by the introduction of his producer.

Mr. Tookey said that he would have appreciated some further information from Mr. Dowson in connection with the tar problems. Engineers required some more definite guidance than was at present procurable upon the different treatment recommended by makers of gas plants. There were some who said that the tar evolved ought to be burnt in the producer itself—Mr. Dowson was apparently of that opinion. Others said that the proper place for the tar was in a bucket, and it should be extracted from the gas by means of a series of coolers before "scrubbing." It seemed to be a matter of opinion whether it was best to separate the tar in such a manner or first to cool the gas in scrubbers and afterwards to extract the tar by copious drenching with water, and with or without mechanical separation such as by means of centrifugal appliances. On the other hand, engineers were informed that during the process of tar separation no water should be allowed to come into contact with the vapours, as when this was permitted, the recovery of the tar was considerably hindered and made a more expensive operation. He thought that if the author could deal with this subject at greater length he would be conferring a benefit upon engineers generally.

Another matter that had not been touched upon by the author was the utilization of fuels other than coal; such as waste woods, leather cuttings, and combustible trade-waste generally. There were many factories throughout the United Kingdom and elsewhere, the proprietors of which would be very glad to install a gas-producer that would gasify waste wood, either in the form of sawdust, or wood chunks, or planer chips that accumulated so seriously in moulding and joinery works. Could the author supplement the information given in the Paper under discussion with some remarks upon this important subject?

(Mr. W. A. Tookey.)

In view of the varying results following the injection of steam in the gas-producer in the manner dealt with in Mr. Allcut's Paper, could Mr. Dowson give any information respecting the introduction of exhaust gases from engine cylinders into the furnace of gas-producers in place of steam? Some particulars had been published —the speaker believed from American sources—upon this subject, and it was claimed that not only had the results been conducive to improved economies, but that as a result of the reduced proportion of hydrogen in the gas delivered to the engine cylinder, the working of the installation as a whole had been found to be more reliable.

Mr. J. **EMERSON DOWSON** said that, before replying to the various points raised in the discussion, he would first deal with Mr. Longridge's complaint that his Paper was merely that of the practical man, and that the theory of the subject had not been dealt with. He explained that he had been asked to compress the reading of his Paper so as to give time for another Paper by Mr. Allcut, and for this reason he had omitted several analyses and results of tests which were given in the Paper. Possibly this had somewhat misled Mr. Longridge. He admitted that he had not dealt fully with all the theoretical questions involved, as this would have made his Paper too long, but he had endeavoured to give a blend of the general theory and practice of the various types of producers he had mentioned. No one could be more impressed than he was with the importance of considering the theory as well as the practice of such a technical subject; the mere practical man with empirical rules could not succeed. Mr. Longridge complained that no definite information had been given as to why difficulties occurred in the working of gas-producers and how to get over them. [illegible] lso said that he had not stated what was a sufficiency of steam [illegible] Dowson pointed out that on pages 319 and 321 he had compar[illegible] effect of working with and without steam, and had speciall[illegible] ed out that the presence of steam reduced the work[illegible], and that this not only checked the formation of cl[illegible] a greater absorption of sensible heat by the gas. As to what he considered a sufficiency of steam, he stated quite definitely on page 324 that for anthracite he found it best to use from 0·5 lb. to 0·7 lb. per pound of fuel gasified. On the following page he pointed out that from a gas-engine point of view it was better to limit the quantity of steam, but that to check the formation of clinker in the producer and to reduce the loss of sensible heat, a liberal quantity of steam was desirable. It was impossible to give a general rule applicable to all producers and all fuels. The Paper stated that for engine work it was generally considered best to compromise the matter by having 12 to 15 per cent. of hydrogen in the gas. As to the depth of fire which was best for making good gas, it depended a good deal on the size of the producer and on the nature and size of the fuel. With anthracite in pieces about 1½-inch to 3-inch cube, the fire should be 3 to 6 feet deep, according to the size of the producer. With anthracite from ⅜-inch to ¾-inch cube the fire was usually 2 feet 6 inches to 4 feet deep, according to the size of the producer. With bituminous coal or with coke the depth of the fire should be greater, the actual depth depending on the size and nature of the fuel.

Mr. Longridge also referred to the construction and corrosion of scrubbers, but the Paper dealt with producers only, or a good deal might have been said about scrubbers and cleaning apparatus. As to Mr. Longridge's suggestion that there was risk of explosion if the cock on the waste-pipe of a producer were left open during the night, he thought this was a mistaken idea. For many years he had worked producers in this way and did not remember a single mishap on this account. As a matter of fact when a producer was stopped, with a fire in it, and when the cock on a waste-pipe was opened, it was like an ordinary slow-combustion stove. He failed to follow Mr. Longridge's explanation that when there was a fire in the producer, with the bottom door open, air could come down the waste-pipe and enter the lower part of the adjoining scrubber. Under these conditions and with the waste-pipe open, there must be an up draught through the waste-pipe. Moreover, in all well-made plants there was a water-seal in the base of

(Mr. J. Emerson Dowson.)

the scrubber next to the producer, or in a separate seal-box, and there was a test-cock on the outlet of the producer. It was somewhat strange that Mr. Longridge should suggest these as novelties.

Replying to Captain Sankey (page 373) as to the heat efficiency of a gas-producer working an engine under different loads, he would point out that when a suction plant was coupled to an engine there was no easy way of measuring the volume of gas produced. Nor was the fuel consumption an exact basis of calculation for the producer alone, as it included an allowance for the engine itself; there was also the difficulty of measuring accurately the small fuel consumption with light loads. Table 2 (page 336) gave the analyses of gas he had made during one of Captain Sankey's engine-tests at Derby, at full load, half load, quarter load, and no load. They were interesting and instructive, but they did not show the efficiency of the producer alone for the reasons above stated. The best examples he could give for full load efficiencies were the careful tests made for Mr. Dugald Clerk's "James Forrest" Lecture in 1904. A 30-b.h.p. plant worked with anthracite gave a heat efficiency of 75 per cent. with a cold start and 83 per cent. with a hot start. A 40-b.h.p. plant worked with anthracite gas gave a heat efficiency of 85 per cent. with a cold start and 90 per cent. with a hot start. This same plant was afterwards worked with coke and then gave a heat efficiency of 84 per cent. with a cold start and 89 per cent. with a hot start. These plants were worked with a suction-fan, so that the volume of gas produced could be measured. He did not know of any data which would show the heat efficiency of a suction-producer at half or quarter loads.

As to the calorific powers given in Table 1 (page 333), they represented the higher scale, and for engine work the lower scale should have been given. They would be about 10, 12, and 11 B.Th.U. less respectively. If the gas were used for heating work the higher scale should be taken. He did not agree with Captain Sankey that an engine worked equally well with a gas of higher or lower calorific power in all cases. This was only true within certain limits, and it was well known that all gas-engines were rated higher for town-gas than for producer-gas.

In answer to queries put by Mr. Hutchins and Mr. Livens, the author stated that his double-blast producer worked satisfactorily with varying loads, and there was no blocking of the vaporizer. Producers of this type were working with coals from various districts, the only restriction being that the coal must not be of a badly caking kind.

As to Mr. Tookey's remarks about tar, he believed there could not be any economical advantage in saving it for sale, as it involved a more expensive plant and a greater cost in working. Apart from this he considered that tarry gas was a real bugbear for a gas-engine, and there had been numerous failures of a serious nature on this account. He had set himself the task of making bituminous gas without tar, and he firmly believed that this was sound in theory and practice. Beyond a few experiments he had not dealt with waste wood, but he knew that a few plants were working with it; it was a subject to which increased attention was being given. As to sending exhaust products of combustion from an engine into the gas-producer, this could be done to a limited extent, but the addition of nitrogen to the combustible gases was a practical drawback. He had inspected a plant in France where this was tried, but it was afterwards given up.

In conclusion, Mr. Dowson commented on Mr. Allcut's Paper. He welcomed him as a new-comer in the field of investigation, but he was obliged to call attention to the fact that the producer he tested was defective and that the results must have been vitiated. The author admitted (page 355) that there were cracks in the brick lining, so that some of the gas was burnt in the upper part of the producer, owing to leaks of air. All who have had practical experience with producers know that this must have prejudiced the results, and he wondered that Mr. Allcut did not make a new set of tests after having the lining put right. Another important defect was the vaporizer used, and the author admitted that it was wrong, as on page 364 he said that owing to the "inefficiency of the internal steam-coil" he was obliged to use a large proportion of

(Mr. J. Emerson Dowson.)

air. The result was a low percentage of hydrogen and a high percentage of nitrogen, and the effect of this was seen in the low calorific power of the gas produced.

It was greatly to be regretted that Mr. Allcut did not make his tests with a well-designed producer (of larger size) which could be taken as fairly representative of this class of apparatus as it was used. Also as to the fuel consumption, it was not sufficiently exact to fill the producer to a given level at the start and finish, as this made no allowance for the space occupied by clinker and ash. The producer should have been emptied after each test, and the unburnt fuel and ash should have been weighed separately. This had a direct bearing on the heat efficiency.

It would also appear that all the hydrogen in the gas was supposed to be derived from the steam decomposed, whereas it was certain that some of it was due to hydrogen in the anthracite. Mr. Dowson had known the latter to contain as much as 5 per cent., whilst only 0·5 per cent. was accounted for by the methane present in the gas; but in any case the anthracite used should have been analysed.

Mr. E. A. ALLCUT, in reply, said that at the outset he would like to endorse all that had been said about Mr. Dowson with regard to the practical assistance which his work in connection with producer-gas had been to both practical and theoretical men, and it had been of great help to him (Mr. Allcut) in all the investigations he had made on producer-gas.

He would like to thank Mr. Longridge for the very kind words he had said about theorists in general, and his (Mr. Allcut's) work in particular. Mr. Longridge had shown a great appreciation of the object of the Paper by plunging at once into the heart of the subject, namely, the effect of the depth of fuel bed. That was rather a by-product of the actual research work, but it was a matter of great importance. In fact, the depth of the fuel itself, and the ratio between the zone of active combustion and the total depth, were the crux of the whole theory and practice of gas-production. He believed that the depth of the zone of active combustion depended very largely upon the velocity of the air through the fuel.

With regard to Mr. Hutchins' remarks (page 378), that gentleman showed a singular lack of appreciation of the points involved in the research. Mr. Hutchins might view the matter from a practical standpoint and emphasize the differences due to other conditions, but, in a series of experiments which were designed to find out certain points, it was advisable, and, in fact, imperative to keep to one variation only. It was of vital importance in this case to take everything constant except the amount of steam. If he had, as suggested, put the air in with the steam, or heated the air, those experiments would not have been comparable with the other experiments of the same series. He had appreciated these points at the time, and had just finished another set of experiments on a gas-producer with heated air, the results of which, however, he had not yet had time to work out. Mr. Hutchins commented upon the remark that the steam consumption varied between 0·5 lb. and 2·5 lb. The object of mentioning that point was that a higher amount than ¾ pound of steam per lb. of coal was useless in the case of small producers, but in any case if an excess of steam were used beyond the quantity that could be efficiently decomposed inside the producer, that steam was carrying off a considerable amount of latent heat which had to be recovered somehow. Unless some regenerative process was used, thus adding to the cost of the producing plant, then that heat, which formed a large proportion of the total heat, was entirely lost, with a consequent fall in the efficiency of the producing plant.

Mr. Livens had mentioned the difficulty of controlling a small producer (page 381). That was a practical difficulty, which he thought he had overcome to a very large extent, by the use of a fan which gave a constant pressure of air inside the ash-pit, by using anthracite coal which did not cake, and by running the producer for about four hours before taking any readings whatever, in order to get the conditions as steady as possible during the series of trials.

(Mr. E. A. Allcut.)

Mr. Dowson's remarks mainly consisted of criticisms on the apparatus used. He might mention that a research student at a University had not unlimited money at his disposal; he had to take the best apparatus he could get. No doubt the University of Birmingham would have been very pleased if Mr. Dowson had come forward with the offer of a gas-producer for the purpose of experiment, and he, personally, would have been only too pleased to experiment with it. As it was, and having only a limited time at his disposal, he had had to take the only producer that it was possible to obtain.

With regard to the cracks in the lining, which Mr. Dowson said vitiated the value of the experiments, he (Mr. Allcut) looked upon the matter in the following way. The cracks were exceedingly small; there was neither time nor money to put in new lining, but a constant pressure of air was kept inside the ash-pit through all the experiments, and, as far as he could observe, the cracks did not expand any further during the series of experiments. The volumes of air which passed up the cracks and burnt in the gas at the top of the producer were thus practically constant, and so a constant percentage of carbon dioxide was produced throughout the trials. If that was assumed, then, although the absolute value of CO_2 might not be the least obtainable, yet the comparative results would be correct, as also would be the point at which the maximum efficiency was obtained.

With regard to the inefficient vaporizer, he could endorse all Mr. Dowson's remarks, as a large proportion of air had to be used to keep the vaporizer at the temperature required to produce sufficient steam for the process. Mr. Dowson was of opinion that all the water-feed might not be vaporized, but if that had been the case, some of the water would have been left in the bottom of the producer at the end of the experiment. There was nowhere else for it to go. As this did not happen, he (Mr. Allcut) assumed that all the water which was not decomposed passed through the fire into the washer. The accuracy of the fuel consumption was rather a sore point at the time; he would have liked to estimate the percentage of clinker and ash formed during each experiment, but the design of the producer forbade that. It would be noticed that the producer had a drop grate, and when it was shut down after each experiment all the clinker was above the bars, and some of the ash below them. On dropping the bars to clean out the producer, the coal, clinker, and ash were so mixed up together that it was impossible to separate them, otherwise, his original intention was to have weighed the amount of clinker and ash formed. If this had been done, no allowance could have been made for the ash formed during the starting period, so that such results would still have been inaccurate. The amount deposited, however, by the pure Welsh anthracite coal in the 4-hour trial was very small indeed; in fact, it was barely discernible. This point, however, in no way affected the accuracy of the results obtained, as the apportionment of the various losses did not come within the scope of the Paper. The coal used in the trials was not analysed, as there was no apparatus in the laboratory for making such an analysis. As the same quality of anthracite was used in all the trials, and the conditions, with the single exception of the amount of steam, were practically constant throughout, it was certain that if any hydrogen came from the coal, an equal amount would be present in each gas analysis. In this respect, again, the comparative results of the trials, he maintained, were perfectly correct.

Communications.

MR. WILLIAM ALEXANDER wrote that he thought the most interesting part of Mr. Dowson's Paper dealt with his double-acting producer, the details of which were stated as having taken a long time to perfect, but unfortunately were not described. For history he directed them to two rather out-of-date publications, neither of which referred to the double-acting producer by the

(Mr. William Alexander.)

French expert Lencauchez.* This producer was practically the same in principle and action, the chief difference being in the section outline of the brickwork next the fuel. Mr. Dowson concluded with well-known comparisons of standby losses for steam and producer plants, which, like many other sections of the Paper, were taken from his and Larter's book.

The most remarkable result of Mr. Allcut's research was that, in a producer of very small size and of admittedly crude design, the proportions of steam and coal for maximum thermal efficiency should be the same as were obtained in average practice with large producers. This result should go towards disposing of the allusions made, in the short discussion that had already taken place, as to the exclusive and valuable information on producer design possessed by manufacturers, which information it was not to their interest to disclose. The rules for design were rough and ready enough, and they might be said to have been for a long time common property. They must necessarily be of an approximate nature only as the output depended a good deal on the nature of the fuel, whether coke or coal, whether in small or large pieces, and so forth, and as it did not pay to modify designs to suit every kind of fuel likely to be used.

As regards the relation between sizes of fuel pieces and depth of generator and other conditions, the following might be of some interest: In the four hypothetical producers here considered the practical desideratum was provided for, namely, that the suction on the engine was the same for the large and the small generators. First, let them consider two generators in which the kind, the depth, and the size of the fuel, the proportions of air and steam, and the flow of the gases per square foot of cross-section were the same for both, but let there be a difference in the diameters. It easily followed, neglecting the effect due to small disproportionate radiation losses, that the difference in pressure between the top and bottom, the fuel consumption per square foot of cross-section, the axial curve of temperature, and the quality of the gas would be the same for both, while the power would be proportional to the diameter squared. Therefore with the conditions assumed, the depth of fuel required for best quality of gas would be the same for large and for small producers.

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* Zeitschrift des Vereins deutscher Ingenieure, 1905.

Now, secondly, since in practice the smaller producers had a less depth, let them assume that the large and the small had depths and size of fuel in proportion to their diameters, and that the other conditions were the same as in the first comparison. Then, by applying the ordinary law of resistance to the flow of gases, it could readily be shown that the suctions on the engine would again be the same for both, and also the power would again be proportional to the diameter squared. As regards the quality of the gas, this was a function of the velocity and the degree of incidental eddying or turbulent motion during the passage through the fuel. The eddying was probably proportional to the loss of pressure, and therefore equal for both producers. Thus the quality would be the same as far as the effects of velocity and eddying were concerned. But the duration of contact of the gas and the fuel was another factor that affected quality. This duration was less for the smaller producer, and the quality would be inferior (supposing it correct for the larger), for there was less time for the necessary chemical action to take place. Hence it was that smaller generators were made a little deeper in proportion to their diameters than large ones. Another influence in the same direction was that the size of the fuel for small producers was not so small proportionately as for those of greater capacity.

From the above considerations, it was an advantage to design the generator so that considerable variations in the depth of fuel could be obtained, for it was in many cases difficult to provide that either the quality or the size of fuel was of a constant average value. It was important that, in virtue of deeper fuel giving a longer path, the flow of gases could be increased in proportion in order to give the same duration of contact. Consequently for high power (which varied as gas flow) per square foot of section the fuel must be deep. Mr. Allcut's suggestion as to making the thickness of fuel as small as possible would involve

(Mr. William Alexander.)

low power and would therefore not be feasible commercially, as in order to keep down cost, high output without reduced quality was desired.

A disproportionately small effect of velocity change on quality might be seen on comparing tests D and E (pages 360–61). The ratio of water supplied and steam decomposed to coal were the same, the velocities of air and gases were about 7 per cent. greater for trial D, while the quality, calorific value, and presumably the depth, were the same for the two trials. This result was suggestive but was not sufficient, of course, to enable it to be said that velocity had in general small effect on quality. It seemed there was occasion for a thorough and systematic research with producers of large and small size on the effect of varying the depth and size of fuel, the velocity of the gas, and other conditions for the determination of efficient maximum output.

Mr. HORACE BOOT wrote that Mr. Dowson referred (page 338) to the quality of the gas being at fault in suction plants that ran at light loads or overloads. The writer had for some time been endeavouring on plants under his care to get rid of this trouble, for it was a very real one, and not only did it cause considerable annoyance in running the engine but the economy of the gas-engine was entirely lost. He found the most suitable way to overcome the difficulty was to instal a small fan. With regard to overloads, it was much more difficult; for seeing that it was impossible to increase the initial pressure or vary the arrangement of cut-off in proportion to the load, it appeared that it must be one of the inherent difficulties of all adiabatic engines. He had experienced the same trouble with overloads on a Diesel engine power-plant he was running at Chichester, and apparently with those engines the most satisfactory and best running load was three quarters of the rated full load. In this power plant there were three engines, two of 150 h.p. and one of 250 h.p. However, Diesel engine plants were perfectly stable at light loads and could be thoroughly relied upon. At the same time, in the case of this type of engine the cost of repairs came out considerably higher than it did with the gas-engine.

Mr. Dowson spoke of the tarry vapours to be got rid of in the producer (page 342). To a large extent, the writer was in accordance with Mr. Dowson in desiring to design the producer in such a manner that the tarry vapours should be got rid of in the producer and avoid having to cool the gas down, as had to be done in so many instances. When he (Mr. Boot) was in Mexico last year he was surprised to find at the Electric Power Co.'s Works for the supply to the town of San Louis Potosi, that they were running a number of large gas-engines on producer-gas and that gas was made from the bark of trees, scrub, sawdust and any waste wood. In this case the producers were specially designed to enable it to be done. The principal difference in the producers was that the gas was taken off at the bottom and used without any washing or scrubbing. On pages 344–5 Mr. Dowson stated that the engine-valves were only cleaned once in three months, and later on, in the case of another engine, they were only cleaned once in five months. It would have been more useful if Mr. Dowson had given the number of hours the engine was actually running, because one could only imagine that the engine whose valves only required cleaning once in every five months, during that five months did not do more than fourteen days' continuous running. The writer's experience of gas-engines when using various classes of fuel, and also with Diesel engines and ordinary oil engines, went to show that unless one was prepared to clean and inspect, every fourteen days, the exhaust-valves and also give special attention frequently to the needle-valves, one could not expect satisfactory running.

On the last two pages of Mr. Dowson's Paper he attempted to make out a very strong case for gas. The writer had had under his care for some time a large steam-driven plant, gas-engine plant, and for two years a Diesel oil-engine plant, and to a certain extent he was in a position to judge of the relative merits and saving to be effected by them. He could not agree with Mr. Dowson in the standby losses of steam-power plants, and especially with regard to water-tube boilers, for he had figures extending over some considerable period showing that although the steam-driven plant was not so efficient as a gas or oil plant, that it was nothing like so

(Mr. Horace Boot.)

inefficient in standby losses as Mr. Dowson represented it, and for large works it possessed many qualities which were not contained in gas or oil engines.

Mr. G. KENYON ROGERS wrote that there was one point in Mr. Dowson's Paper which struck him as a possible source of trouble in such a country as India, especially in places where only native labour could be obtained. He referred to the form of the lining in the top part of the generator which was sloped inwards. As building the generator with vertical sides would be a much simpler form of construction, he wished to ask if it were essential that the walls of the upper part should slope inwards as shown, and if so, was any particular angle of slope desirable.

Mr. E. A. ALLCUT wrote in further reply to Mr. Dowson's remarks, that it was interesting to note that on page 324 of his Paper on "Gas-Producers" he said "The weight of steam decomposed varied between 0·5 lb. and 0·7 lb. per pound of coal gasified." As the best results obtained in his (Mr. Allcut's) trials were about 0·53 to 0·54 lb. of steam decomposed per pound of coal, it was evident that the accuracy of the results was not greatly affected by the alleged defects of the apparatus.

He quite agreed with Mr. Alexander (page 392) that the rules for the design of gas-producers must necessarily be approximate, owing to the variable nature of the fuels used in them. Further, Mr. Alexander assumed that the gas produced in a deep fuel-bed was better than that from a shallow one, because the time of contact between gas and fuel was greater in the former case than it was in the latter. But this was not necessarily true. One of the points upon which he (the author) laid most stress in his Paper was the theory that the gas-producing process was completed in a very short time, so that a layer of 2 to 3 feet of fuel was sufficient to generate good gas. Beyond this depth any superincumbent layer of cool fuel was actually detrimental in disturbing the equilibrium of the gas-producing reactions, and yielding a poorer gas. This theory was supported by experimental evidence in his own research and also in a further Paper by

Dr. Bone and Dr. Wheeler,* which had been brought to his notice since the reading of his own Paper. A series of trials was made upon the same Mond plant as was used in the 1906 trials, but with a coal depth of 3 feet 6 inches instead of 7 feet. It was found that the quality of gas obtained with the shallow depth of fuel-bed was substantially the same as that produced by the deep fuel-bed. Moreover, during the daytime the producer was worked with an overload of 47 per cent., which showed that the velocity of gas through the fuel, within reasonable limits, did not greatly affect the composition of the gas, and also that a deep fuel-bed was not necessary to provide sufficient time for complete gasification. It was particularly gratifying to find that his results, and the theories derived from them, were supported by such weighty evidence.

Mr. DOWSON wrote, in reply to the written communications, that he had no knowledge of the Lencauchez double-blast producer referred to by Mr. Alexander, or of any results obtained with it. He noted that the reference to this producer was dated 1905, whereas his own was dated 1903.

In reply to Mr. Boot (page 395) he would say that the engines referred to on page 344 were usually worked from 9 to 12 hours a day, and the one mentioned on page 345 was worked about 8 hours a day. The following were his authorities for the standby losses with steam power:—

1. Various	Mr. Deeley, Loco. Supt., Midland Railway.
2. Lancashire	Mr. Henry Lea.
3. Babcock and Wilcox	Col. R. E. B. Crompton.
4. Ditto	Ditto.
5. Ditto	Mr. A. Collings Bishop.
6. Ditto	Ditto.
7. Niclausse	Messrs. Willans and Robinson.
8. Lancashire	Mr. F. A. Wilkinson.

Replying to Mr. Rogers (page 396), he would say that the form of the producer lining was fairly simple, but that however simple it might be, the bricks should be set by a skilled bricksetter and not by a mere labourer of any nationality.

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* Journal, Iron and Steel Institute, No. III, 1908, page 206.

NOTES ON BRONZE PUMPS IN THE BRITISH MUSEUM.*

By Mr. JAMES P. MAGINNIS, *Member*, of London.

[*Selected for Publication.*]

The accompanying photographs and drawing, Plate 21, are of two bronze pumps found at Bolsena, Etruria, and now in the British Museum, London. The label attached describes them as "Parts of Two Roman Fire Engines (on the principle invented by Ctesibius of Alexandria)," who is said to have lived in the Third Century B.C.

The larger of these pumps consists of two vertical cylinders connected at the base by a horizontal pipe leading into an uptake or delivery-pipe common to both. Each cylinder contains a ram or plunger with a knuckle joint and a hollow socket for the attachment of the pump-rods. A portion of the horizontal pipe referred to has been cut away, and reveals two flap-valves of bronze with suitable valve-seats at the base of the uptake or delivery-pipe. These valves consist of disks bolted or riveted loosely to the seats, thus allowing freedom to flap and open or close the passages as the rams were moved upwards or downwards. Foot-valves of a similar type no doubt were placed in each cylinder, but these do not remain on the pump referred to. A valve and valve-seat, however, form part of the exhibit, and these may have been thus used.

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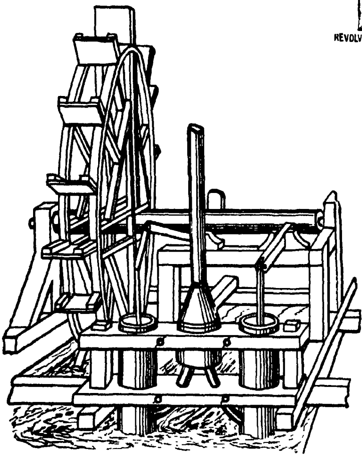
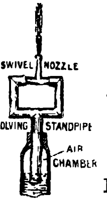
* Referred to by the President in his Presidential Address, Proceedings, 1911, Part 2, page 215.

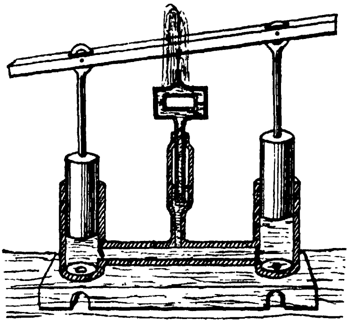
Both the plungers are hollow, and it has been suggested that they were so formed in order to provide a means of introducing a plug of wood, perhaps covered with hide or leather, in order to make a watertight fit; but the author is inclined to believe that such was not the case, for Vitruvius in describing a similar pump speaks of "pistons turned very smooth and anointed with oil,"* which suggests

Pumps driven by Water-wheel, Ctesibius.
(Reduced from Ewbank's Hydraulics and Mechanics, p. 267.)





† *Egyptian Fire-Engine of the 2nd Century B.C. from Heron's Spiritalia.*
(Reduced from Ewbank's Hydraulics and Mechanics, p. 305.)



the use of a lathe or turning machine of some sort, and an illustration of a pump is shown, driven by a water-wheel (*see* Sketch). On page 305 of the same book* is shown a section of a pump which has a striking resemblance to that in the British Museum, in which may be seen an air-vessel (*see* Sketch) and also a curious technical error. On referring to a drawing in Hero's "De Pneumatica,"† it may be seen that the rectangular chamber at the top of the delivery-pipe was intended to act as a swivel, so that the fireman might direct the jet of water in any desired direction. A sketch of the swivel nozzle from this book is shown. Through an error of a draughtsman this is shown on the former drawing as of rigid construction, and, consequently, would not answer the intended purpose.

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* Ewbank's "Hydraulics and Mechanics," 1847, page 266. (*See* Appendix, p. 402).

† Hero's (or Heron's—*Ency. Brit.*) "De Pneumatica"—Greenwood's translation. Ed. Bennett Woodcroft. 1850. Page 44.

The pump in the British Museum is, unfortunately, so encrusted and corroded that it is not easy to say with confidence whether its parts had been turned and bored, but there is some evidence of turning on one of the plungers, which may be seen in the photographs, and the excellent fit of the spigot and socket joining together the parts of the horizontal pipe, where sawn through, suggests similar treatment.

A smaller pump of a somewhat similar type is shown on Plate 21, in which the valves are of the stem- or mushroom type. Above the photograph of the larger pump appears what are evidently the trunnion and bearing of the horizontal beam operating the pump-rods of the larger pump.

These pumps were partially submerged in water during operation, slightly raised from the bottom of a tank on the bed of a stream, and were not called upon to lift the water, but only to force it upwards. This is clearly shown in the illustrations referred to.

The Paper is illustrated by Plate 21 and 3 sketches in the letterpress, and is accompanied by an Appendix (page 402).

APPENDIX.

Ewbank's "Hydraulics and Mechanics," 1847, *page* 266.

"It remains now (says Vitruvius) to describe the machine of Ctesibius, which raises water very high. This is made of brass; at the bottom a pair of buckets (cylinders) are placed at a little distance, having pipes like the shape of a fork annexed, meeting in a basin in the middle. At the upper holes of the pipes within the basin are made valves, hinged with very exact joints, which, stopping the holes, prevent the efflux of the water that will be pressed into the basin by the air. Upon the basin a cover like an inverted funnel is fitted, which is adjoined and fastened to the basin by a collar, riveted through, that the pressure of the water may not force it off; and on the top of it, a pipe called the tuba is affixed perpendicularly. The buckets (cylinders) have valves placed below the lower mouths of the pipes, and fixed over holes that are in their bottoms; then pistons *turned very smooth* and anointed with oil, being inclosed in the buckets (cylinders), are worked with bars and levers from above; the repeated motion of these, up and down, pressing the air that is therein contained with the water, the holes being shut by the valves, forces and extrudes the water through the mouths of the pipes into the basin, from whence, rising to the cover, the air presses it upwards through the pipe, and thus from the low situation of the reservoir raises it to supply the public fountain."—Book X, cap. 12. Newton's Trans.

CONVERSAZIONE.

A CONVERSAZIONE was held at the Institution on Friday, 26th May 1911, when the Members and their friends were received by the PRESIDENT and Mrs. Ellington in the large Hall, which had been suitably decorated for the occasion. During the evening the Royal Artillery Mounted String Band played selections of music, by permission of the Officers of the Royal Artillery, Aldershot, and a vocal and instrumental Concert was held in the Library. A short Lecture, entitled "Optical Determination of Stress," was given by Professor E. G. Coker, D.Sc., F.R.S.E., and was illustrated by lantern slides. The number of Guests, which included Major-General Sir C. F. Hadden, K.C.B., the Chairman of the London County Council, the Deputy Master of the Trinity House, and the Presidents of some of the Technical Societies, exceeded 900. The President was supported by the following Members of the Council: Dr. William H. Maw, Sir William H. White, K.C.B., Mr. H. F. Donaldson, C.B., Mr. W. H. Allen, Sir John Wolfe Barry, K.C.B., Dr. H. S. Hele-Shaw, and Captain H. Riall Sankey.

The Institution of Mechanical Engineers.

PROCEEDINGS.

14th July 1911.

A Special General Meeting of the Institution was held at the Institution on Friday, 14th July 1911, at a Quarter past Two o'clock p.m.; Edward B. Ellington, Esq., President, in the Chair.

The requisite quorum of thirty Members and Associate Members being present, the Secretary read the notice convening the Meeting, as follows:—

Storey's Gate, St. James's Park,
Westminster, S.W.
6th July 1911.

SPECIAL GENERAL MEETING.

Dear Sir,

I am instructed by the Council to inform you that a Special General Meeting will be held at the Institution on Friday, 14th July 1911, at 2.15 p.m., when the following Resolution will be submitted:—

> "That in view of the proposed extension of the Institution Buildings the Council be and they are hereby authorized to borrow moneys generally for the purposes of the Institution, but so that there shall not be at any time outstanding a greater principal sum than £50,000, and to borrow such moneys from such persons, at such rate of interest, either without security or upon such security, by means of

debentures, mortgages, or charges of the property of the Institution, or otherwise, and upon such terms generally as the Council in their discretion think expedient."

I am, Dear Sir,
Yours truly,
EDGAR WORTHINGTON,
Secretary.

The PRESIDENT asked to be allowed to express, on behalf of the Council, their regret that it should have been necessary to call the members together in such tropical weather for a purely formal matter, but they were acting under Articles of Association, and the discretion of the Council was limited by the By-laws. The Solicitors had advised that in their judgment it was desirable that the Resolution should be submitted to the members and approved by them. On the occasion when the building was erected as it stands today, a somewhat similar course was followed. A certain number of Debentures were issued to provide part of the funds required, and then a Resolution was passed by the members authorizing the Council to borrow an unlimited amount upon such security as they had to give. It was a question whether that Resolution still held good. But the Council thought that it would be straining the intent of that Resolution rather far to make it apply to the present borrowing for the extension of the building, and they considered that it was better that the members should be called together to pass this Resolution. It would be seen that the wording of the Resolution limited the total amount which could be borrowed, at the discretion of the Council, to £50,000.

The financial position with regard to the proposal was as follows: £20,000 of the old Debentures were outstanding, and the intention was to redeem these and to issue a further amount of £20,000, giving a first charge for the total amount of £40,000 Debentures upon the whole of the property of the Institution. He would say, first, that all holders of the old Debentures were given the option of exchanging them for the new Debentures.

Of the £20,000 old Debentures, holders of £13,700 had expressed their willingness to receive the new Debentures in exchange. That left a balance of some £6,000 to £7,000 of the old Debentures to be liquidated. Notice of redemption had already been given to the old Debenture holders who desired to be paid off; and they would be paid off at the end of the year out of the ordinary resources of the Institution. There was a sum of about £15,000 invested in Stocks, a portion of which had been allocated to the Sinking Fund for the redemption of the leasehold property. There were facilities with those Stocks, either to borrow temporarily the amount required to pay off these old Debentures, or some of the Stocks could be disposed of. At any rate, the ordinary financial resources of the Institution, together with the accruing savings of the Institution, which had been recently at the rate of £3,000 per annum, would provide ample funds for the liquidation of the old Debentures.

With regard to the new Debentures, there had been very nearly £20,000 applied for, and the Council were of opinion that the resources of the Institution were ample with these subscriptions to carry out the whole of the works contemplated.

Therefore, they would see that in taking a borrowing power up to £50,000, the Council would be given ample discretion to carry out the work to its completion. They hoped that the work might possibly be completed in the course of next year.

The PRESIDENT then moved the Resolution which had been read by the Secretary.

Dr. WILLIAM H. MAW, Past-President, said he had great pleasure in seconding the Resolution.

The PRESIDENT said that if any members present had any remarks to make, or required any explanations, he would be glad to hear them. (No remarks were made.) He said that he took it that the explanations he had given had been satisfactory.

The Resolution was then put to the Meeting and carried unanimously.

The PRESIDENT thanked the members for their attendance; and the Meeting then terminated.

The attendance was 35 members.

MEMOIRS.

JAMES KITSON, BARON AIREDALE OF GLEDHOW, was born in Leeds on 22nd September 1835, being the second son of the late James Kitson, who, in 1832, had commenced in a small way the engineering works which subsequently developed into the extensive Airedale Foundry, Leeds. The workshop was part of the ground floor of a weaving-mill at Hunslet, and here his first locomotive was built during the year of the birth of his second son, who became Lord Airedale. The subject of this memoir obtained the earlier part of his education at the Wakefield Preparatory School, proceeding later to University College, London, where he continued until nineteen years of age. His father had meanwhile developed his business, and taken complete possession of the whole of the weaving-mill and extended the boundaries. In order to obtain a supply of reliable Yorkshire iron, he purchased the Monk Bridge Iron Works at Holbeck in 1854, and placed it in complete charge of his two sons—the eldest the late Mr. F. W. Kitson,* and the second son, Mr. James Kitson. In 1877, owing to the death of his brother, he had not only to take complete control of the ironworks, but had also to assist his father in the wider responsibility of the engineering factory at Hunslet. The relationship between the workmen and their employers was exceedingly cordial, as was shown on the twenty-fifth anniversary of the association of the firm with the Monk Bridge Works, and the jubilee of the works in 1904. It was the same, too, with the employees at the works at Hunslet, which now cover over a dozen acres, and afford employment to 2,000 workmen. Although the co-partnery was converted into a limited liability company in 1886, Lord Airedale continued to take a most active part. In addition to building locomotives they established other branches of business, notably stationary engines for rolling mills and blowing engines.

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* Proceedings, 1878, page 11.

He was closely associated with many of the technical societies. He became a Member of this Institution in 1859, and on the occasions of the Summer Meetings being held in Leeds, he was always a prominent member of the Reception Committee. He was a Member of the Institution of Civil Engineers, and served for some years on its Council. The Iron and Steel Institute had the first place in his regard, because of his early association with the production of Yorkshire iron. He was one of the original Members of the Institute, and served for a long time on the Council, being President in 1889 and 1890. The Bessemer Gold Medal of the Institute was awarded to him in 1903.

Lord Airedale followed the example of his father by devoting a large part of his time to the advancement of social and educational movements. As early as 1862 he, along with others, instituted the Model Dwellings scheme in Leeds, and encouraged the workers to erect dwelling-houses on a sound commercial basis. Throughout his life he devoted much attention to the education question, in both elementary and higher branches, and in this connection his work was recognized by the University of Leeds in 1904, when the honorary degree of Doctor of Science was conferred upon him, not only because of his liberal support to the funds but because of his help in advancing science and industry. He was also active in developing the commerce of Yorkshire, and was for two years (1880–1) president of the Chamber of Commerce. He was a Justice of the Peace for Leeds and for the West Riding of Yorkshire, and was unanimously elected Mayor of Leeds for 1896–7. During this latter period the dignity of a Lord Mayorship was granted to the city by Queen Victoria. In later years Lord Airedale devoted much of his time to political work. After an unsuccessful attempt to enter Parliament for Central Leeds in 1886, he succeeded, six years later, in being chosen for the Colne Valley, and sat for this constituency until elevated to the Peerage in 1907. A Baronetcy was conferred upon him in 1886, a Privy Councillorship in 1906, and he was raised to the Peerage in 1907 as the first Baron Airedale of Gledhow. While returning from the south of France he was seized in the train with a heart attack, and died shortly after reaching Paris, on 16th March 1911, in his seventy-sixth year.

EMERSON MUSCHAMP BAINBRIDGE was born at Eshott Hall, Northumberland, on 23rd December 1845, being the son of Mr. E. M. Bainbridge, colliery proprietor. He was educated privately, and, concurrently with his period of apprenticeship in Lord Londonderry's collieries, at the University of Durham, where he studied mathematics and mining engineering. He soon established a reputation among those connected with the mining industry. In 1867 he was selected to report to the North of England Institute of Mining Engineers on the haulage of coal, and his efforts were rewarded by a valuable premium. Two years later the Institution of Civil Engineers awarded him the Manby Premium for a Paper upon the probability of working coal at a depth of 4,000 feet. In 1870 the Sheffield and Tinsley Collieries were placed under his supervision, and later he accepted the management of the Duke of Norfolk's collieries. Subsequently he became managing director of the Nunnery Colliery Co., and, with other gentlemen, devoted his attention to the possibilities of large colliery developments in the east of Derbyshire, which met with great success. He next became associated with the promotion of a railway line—the Lancashire, Derbyshire, and East Coast Railway—which was to connect the east and west coasts of England by a line running through the manufacturing and colliery districts, commencing at Warrington and ending at Sutton-on-Sea. The scheme passed through Parliament, but was not sufficiently supported by the public, with the result that only the central sections were constructed, and these after some years became merged in the Great Central Railway. On the occasion of the Summer Meeting of this Institution in Sheffield in 1890, Mr. Bainbridge read a Paper * on Recent Improvements in the Mechanical Engineering of Coal Mines. His wide knowledge of engineering made him a valuable member of the Royal Commission on Coal Dust in Mines in 1891. In 1895 he was elected Member of

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* Proceedings, 1890, page 360.

Parliament for the Gainsborough Division of Lincolnshire, but in 1900 he was defeated. In all the works with which he was connected, he endeavoured in various ways to help the workers. Thus at Sheffield he established a home for waifs and strays, at Bolsover a model village and an orphanage, at other villages co-operative stores, recreation grounds, etc. Among the many directorates upon which he served may be mentioned those of the Lancashire, Derbyshire, and East Coast Railway, the Sheffield District Railway, the Kansas City, Mexico and Orient Railway Co., the New Hucknall Colliery Co., the Yorkshire Engine Co., and various colliery companies in Derbyshire, Yorkshire, and Northumberland. His death took place from pneumonia, in London, on 12th May 1911, at the age of sixty-five. He was elected a Graduate of this Institution in 1869, and was transferred to full Membership in 1890.

HARRY BARRETT was born in Manchester on 3rd September 1875. He was educated at the Scottish High School at Bombay from 1879 to 1888, when he returned to England and commenced an apprenticeship of over five years with Messrs. Daniel Adamson and Co., of Dukinfield, near Manchester. During this period he studied in the engineering department of the Owens College, and obtained honours in various subjects. In 1897 he went for six months as a junior engineer in the employ of the British India Steam Navigation Co., and for another six months he was assistant manager for Messrs. Greaves, Cotton and Co., Bombay. In the following year he returned to England and was employed as leading mechanic of the electrical department of Messrs. Tweedale and Smalley, of Castleton, near Manchester. Three years later he entered the drawing office of Messrs. Daniel Adamson and Co., Dukinfield, where he remained about eight months, and then he proceeded to South Africa as electrician on the Cape Government Railway at Uitenhage. In May 1903, he became engineer to Messrs. Jenkins and Co., of Durban, Natal, where he was engaged in estimating and supervising the erection of electrical and mechanical plant. In 1908 he returned to India and became engineer to Messrs. Greaves, Cotton and Co., of Bombay, in whose employment he remained until his death, which took place in Bombay on 3rd October 1910, at the age of thirty-five. He became an Associate Member of this Institution in 1905.

JAMES CROLL was born at Paisley on 25th January 1878, and was educated at the John Neilston Institute and the Government Science and Art Schools, Paisley. In 1893 he began an apprenticeship at the Caledonia Engine Works at Paisley, and on its termination in 1898 he went to sea as Fourth Engineer, subsequently rising to the rank of Third and Second Engineer in 1902. In the following year he became an engineer in the employment of the Hawaiian Commercial and Sugar Co. at Mauii, Hawaiian Islands, and from 1905 to 1907 he was superintendent and engineer of the Olaa Sugar Co., Hawaii, in which position he had full charge of upkeep and manufacture in the sugar factory, railroads, and transportation plant. During the following two years he acted in the same capacity at the Ingenio Concepcion, Argentine Republic, and in 1909 he became mill manager at Anasco, Porto Rico, subsequently being appointed engineer to the Beira Rubber and Sugar Estates. His death took place from the result of an accident at Beira on 2nd December 1910, in his thirty-third year. He became an Associate Member of this Institution in 1905, and was transferred to the class of Member in 1910.

ARTHUR JAMES GIMSON was born at Leicester on 3rd September 1853, being the second son of Mr. Josiah Gimson who, in conjunction with his brother, founded in 1841 the engineering firm of Gimson and Co., Leicester. At the age of nineteen he was apprenticed to Messrs. Sharp, Stewart and Co., of Manchester, for two years, and then returned to Leicester to become shop manager for Gimson and Co.; under his management the work of the firm continuously increased. Among the various works of which he had the responsibility of carrying out were the sewage pumping machinery for the Corporations of Burton-on-Trent and Leicester, and later the water-supply plant for the Weymouth and West Gloucester Waterworks

Companies, also the deep-well pumping plant for the Rand Water Board, Johannesburg. On the occasion of the Summer Meeting of this Institution held in America during 1904, he went with the party, and on his return contributed a Paper to the Institution on "Some Impressions of American Workshops." * In 1909 he went to South Africa in the interests of his firm, which had been converted into a private company, and returned early in 1910, after a successful tour. Shortly afterwards he developed an illness, which terminated fatally on 25th March 1911, in his fifty-eighth year. He became a Member of this Institution in 1884.

THOMAS ARTHUR GREENHILL was born at Beighton, Derbyshire, on 23rd March 1840. His education was received at Cowley Diocesan School, Oxford, the North London Collegiate School, and privately. In 1855 he commenced an apprenticeship with his father, and, on its completion three years later, he was sent to take charge of the construction of a section of the Marseilles and Toulon Railway for Messrs. Marshall, Garnham, and Greenhill, contractors. He was next placed in charge of the construction of the South Eastern of Portugal Railway, and on the conclusion of the work in 1864 he received from the King of Portugal the decoration of a Knight Commandership of the Order of Christ. He returned to England in 1864, and was then engaged in setting out and preparing designs for the construction of the Lichfield and Sutton Coldfield Railway. During the years 1865–66 he was in Ireland watching the construction of the Kilrush and Kilkee Railway on behalf of the London Financial Association, and this was followed by his being appointed to superintend the construction of the Buitron and Huelva Railway in the south of Spain for Mr. Thomas Docwra, contractor. On the completion of the contract in 1872, he was appointed to construct the Zamora Water Works, and subsequently became managing director in Spain. In the following year he started in practice on his own account, carrying out works alone or jointly with others, among which may be mentioned the Valladolid

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* Proceedings, 1905, Part 1, page 7.

and other water works, Alcoy and Gandia Railway and Harbour, pumping engines for Madrid Water Works and Bilbao Sewage Works, etc. In 1906 he retired from business and returned to England, residing in Bromley, Kent, where his death took place on 20th April 1911, at the age of seventy-one. He became a Member of this Institution in 1901.

John Harry Hallett was born at Fareham, Hants, on 2nd May 1850, and was educated at private schools in Cardiff. He served his pupilage at the works of the Taff Vale Railway, Cardiff, under the late Mr. Joseph Tomlinson,* Past-President of this Institution. On its completion he went to sea in 1871, and in the following year became guarantee engineer to one of the steamers belonging to Messrs. Blair and Co., engine builders, of Stockton-on-Tees. He remained for several years in this position, and had charge of a great number of new engines, during which time his duties took him to all parts of the world. Whilst in the North of England he was employed in several of the shipbuilding yards, including those of Messrs. Pearce and Lockwood, on the Tees, Messrs. Palmer, of Jarrow-on-Tyne, Messrs. Mitchell and Co., of Newcastle-on-Tyne, and Messrs. Irvine, of West Harlepool. Acting on the advice of Mr. Joseph Tomlinson, he started in business at Cardiff on his own account in 1879, as consulting engineer and surveyor, and shortly after, in conjunction with Mr. Joseph Tomlinson, he attended the trials of smoke abatement at South Kensington. Subsequently he conducted some extensive coal-testing experiments in connection with the South Wales steam coals. In 1880 he was appointed Engineer Assessor to the Home Office, which position he held until his death, and during this period he was called upon to enquire into the cause of the casualty to the S.S. *City of Paris*, a breakdown of great magnitude. Subsequently he was engaged in enquiries into most of the accidents of a similar nature. In 1884 he read a Paper before this Institution at the Summer Meeting in Cardiff in 1884, on the "Causes and Remedies of

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* Proceedings, 1894, page 163.

Corrosion in Marine Boilers." * Shortly after this he was appointed Commissioner on Boiler Explosions to the Board of Trade, and in this capacity he held investigations into some of the largest and most important explosions in this country. In 1896 he was called upon to investigate the condition of the machinery at the Cardiff Corporation Electric Lighting Works. In spite of his large professional work, he found time to devote himself to local affairs. He was a member of the Shipowners' Association, and a member of the Technical Instruction Committee for the County Borough of Cardiff, surveyor to the Italian Register and to the French and Belgian underwriters, and a member of the Shipwrights' Company of London. His death took place at his residence at Llandaff, on 10th April 1911, in his sixty-first year. He became a Member of this Institution in 1880; he was also a Member of the Institution of Civil Engineers, and of the Institution of Naval Architects.

Edwin Francis Howlden was born in March 1843. He was educated at the Grammar School, Sheffield, and then entered the works of the Great Northern Railway at Doncaster. Having passed through the various departments, he became foreman in 1865, and eleven years later he was appointed Carriage and Wagon Superintendent, which position he held until his retirement in 1904. Altogether he was in the service of the Great Northern Railway for fifty-one years, during the latter period of which he carried out many improvements to the rolling-stock, etc. His death took place in London on 7th March 1911, at the age of sixty-eight. He became a Member of this Institution in 1904.

William John Jenkins was born at Llangantin, Breconshire, on 12th September 1858, his father being a miller. At the age of seventeen he went to the Midland Railway Works at Derby for a short time, and afterwards to Messrs. G. Fletcher and Co.'s Works, Derby; while there he attended the evening classes at the Science and

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* Proceedings, 1884, page 331.

Art School, afterwards becoming a teacher. Later on he filled for a time the position of Assistant County Analyst. In 1880 he was appointed chief draughtsman to Messrs. W. Allchin and Co., traction-engine makers, of Northampton; and a few years later he joined West's Gas Improvement Co. in a similar capacity, where he was afterwards promoted to the position of manager, an office which he held for eleven years. Upon the death in September 1895 of Mr. Charles Hopkinson, of the Beehive Works, Retford, Mr. Jenkins went to that town, and commenced business as a gas engineer at the Beehive Works, under the title of W. J. Jenkins and Co. Under his management the business increased rapidly. He began work with about forty men, and now (in 1911) the firm employs about 400 men. The experience gained while with West's Gas Improvement Co. was of great use to him in carrying on his business as a manufacturer of retort-stoking machinery. Within eight years, about 120 installations of this machinery, besides a large number of coal and coke handling plants, retort-houses, settings, etc., were carried out by his firm. About three years after going to Retford, finding there was a lack of technical education among the youths who were engaged at his works, he employed a teacher to give lessons in the evenings on the subjects of steam, applied mechanics, and machine construction. Later on, owing to the increasing volume of business, it was found necessary to discontinue them at the works, but he was instrumental in organizing similar classes in the town, under the control of the Nottinghamshire County Council. His death took place suddenly at Retford, on 29th May 1911, at the age of fifty-two. He became a Member of this Institution in 1892; he was also an Associate Member of the Institution of Civil Engineers, and a Member of the Manchester Association of Engineers.

THOMAS SCOTT KING was born at Gainsborough in 1864, and was educated at the Southolme School in the same town. In 1878 he began an apprenticeship with Messrs. Marshall, Sons and Co., and on its completion in 1882 he was engaged as a fitter at Messrs. Lake and Wigley's Works, Nottingham. In the following year he spent six months in the drawing office of Messrs. Manlove, Alliott and Co., Nottingham, and then re-entered the works of Messrs. Marshall, Sons and Co., as foreman successively of the testing department and then the engineering department. In 1890 he was engaged with Messrs. Robey and Co., Lincoln, first as leading draughtsman until 1892, and then as their London resident engineer during 1892–93. In the latter year he was appointed manager of Messrs. Clench and Co.'s Works, Chesterfield, which position he held until 1897, when he became engineer at Messrs. Davey, Paxman and Co.'s Works at Colchester. This position he held until 1904, when he started in business on his own account in Cardiff, and devoted himself to the development of his numerous inventions. Among these may be mentioned: a two-course expanding-flow superheater; pneumatic hammers; a pattern-making machine; apparatus for improved boiler-feed, etc. His death took place at Penarth on 20th March 1911, in his forty-seventh year. He became a Member of this Institution in 1895.

RICHARD HOBBS TAUNTON was born at Wareham, Dorsetshire, on 1st June 1831. A few year later his parents settled in Birmingham, and he became a pupil of King Edward's Foundation. As he showed some mechanical talent he entered the service of Messrs. Fox, Henderson and Co., of London Works, Smethwick, and soon became an outdoor superintendent. Among his early responsibilities he had the oversight of the erection of roofing at Sheerness Dockyard, and after that he was second in charge in connection with the erection of the roof of New Street Station, Birmingham. This was followed by his being superintendent of the erection of the bridge over the River Medway on the London, Chatham and Dover Railway at Rochester. He next became manager of the foundry department of Messrs. Cochrane and Co.'s Woodside Ironworks, near Dudley, and for them he superintended the erection of various bridges. In 1862 he bought the Star Tube Works. In addition to tube manufacture, general engineering work was carried out, and particularly high-pressure cylinders for the Government balloon department. He was an active member of several trade organizations, and for several years was chairman of the Boiler Tube Association. Owing to the growing demand for seamless cold-drawn tubes, incident to the development of cycle-building, his firm was converted into a limited company, as Taunton, Delmard and Lane, but the enterprise was unsuccessful. His death took place at Witton, near Birmingham, on 29th March 1911, in his eightieth year. He became a Member of this Institution in 1876.

William Isaac Taylor was born at Auckland, New Zealand, on 17th July 1849. He entered Messrs. Losh, Wilson and Bell's engineering works at Walker-on-Tyne as an apprentice in January 1863, and served four years in the fitting shops and two years in the pattern shop. He then entered the drawing office, where he remained seven years, ultimately becoming head draughtsman and assistant manager. In 1876 he started a consulting engineering practice in Newcastle-on-Tyne, in partnership with Mr. Alfred Goodman, a business which he continued for a period of two years, when he accepted the position of engineer and manager of the Barmoor Colliery, near Lowick, Northumberland. From 1882 until quite recently, he acted as London manager for, and was a director of, Messrs. Clarke, Chapman and Co., of Gateshead, and for a long time, and up to the date of his death, he had acted as London representative of the Darlington Forge Co. His death took place suddenly at his residence at Bush Hill Park, Enfield, on 10th March 1911, in his sixty-second year. He became a Member of this Institution in 1896; he was also a Member of the Institution of Naval Architects, the Institution of Electrical Engineers, and the Institute of Marine Engineers.

Percy James Tunley was born at Gainsborough on 5th May 1875. He was educated at the Grammar School, Gainsborough, from 1886–89, and then served two years in the drawing office of Messrs. Marshall, Sons and Co., of that town. He next entered the works of Messrs. Amos and Smith, marine engineers, Hull, passing through the shops and drawing office. Five years later he went to sea as Fourth Engineer, subsequently becoming Third and Second Engineer, and in 1899 he obtained his First class Board of Trade Certificate. In January 1900 he was engaged as draughtsman at the electrical works of Messrs. Crompton and Co., Chelmsford, and in October of the following year he went in a similar capacity to Messrs. Siemens Brothers and Co.'s works at Woolwich. In 1908 he was sent by the firm as engineer at their works in Madras. Early in 1911 he went to England on leave, and on his return to Madras in June, he was taken ill and was advised to proceed to England immediately. His death, from heart failure following on acute bronchitis, took place, before reaching Colombo, on 28th June 1911, at the age of thirty-six. He became an Associate Member of this Institution in 1902.

WILLIAM LAWRIE TURNBULL was born in Glasgow on 3rd July 1870. He was educated at the High School and Allan Glen's School, Glasgow, and attended engineering classes at the University of Glasgow. His apprenticeship of five years was served partly in the works of Messrs. Clarkson Brothers and partly at the Canal Basin Foundry, Port Dundas, Glasgow, after which he was engaged in the drawing office of his father for three years. In this connection he designed and superintended the erection of various water-power plants in Great Britain. He then went to America for a short time to study the water-turbine business, and after his return he joined his father as partner, the firm becoming John Turnbull, Jun., and Sons, consulting engineers. Amongst some of the later work with which he was connected may be mentioned the installation of several large "Hercules" turbine sets. His death took place at his residence at Bridge-of-Weir, Scotland, on 20th February 1911, in his forty-first year. He became a Member of this Institution in 1904; he was also a Member of the Institution of Engineers and Shipbuilders in Scotland.

FRANK THORNTON WEBSTER was born at Sheffield on 22nd September 1875. He was educated at private schools in Sheffield, and later at the Sheffield Royal Grammar School. He served an apprenticeship of six years, 1890–96, at the works of Messrs. T. Firth and Sons, Sheffield, and, after being in the drawing office for several years, he specialized on the designing of projectiles, mostly of the armour-piercing type. He also carried out much useful work on hydraulics, both for large forging presses and also presses for drawing shell. During the latter part of his time he made a special study of the Harmet process of compressing steel, and he was engaged on this special work at the time of his death, which took place in Sheffield on 18th January 1911, at the age of thirty-five. He became an Associate Member of this Institution in 1906.

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WILLIAMS, C. T., elected Associate Member, 211.
WILLIAMS, Sir E. L., Decease, 125.
WINN, C. R., Decease, 125.
WINTER, W., elected Associate Member, 310.
WISE, Sir W. Ll., Decease, 125.
WOLFE, J. E., Decease, 125.
WRAY, G. H., elected Graduate, 212.

YOUNG, T. K., elected Graduate, 212.

Plate 1

ROTHESAY DOCK

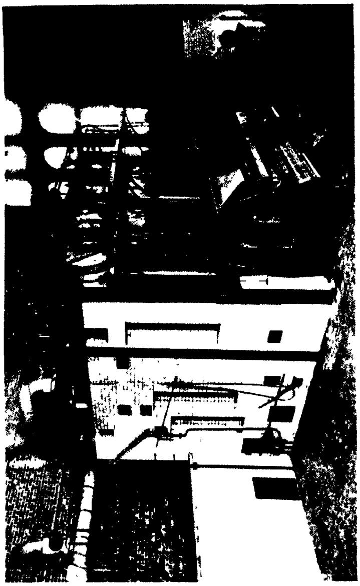


Fig. 3. *Interior of Boiler-House, looking East.*

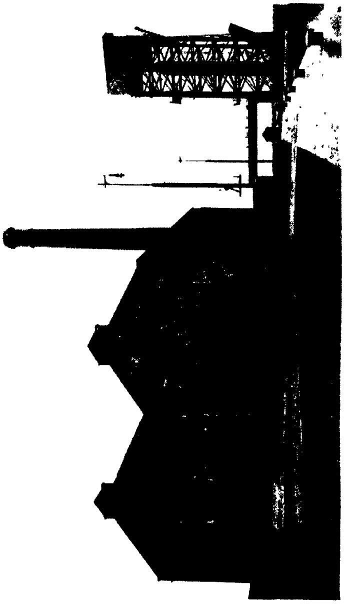


Fig. 2. *Generating Station and No. 2 Coal-Hoist.*

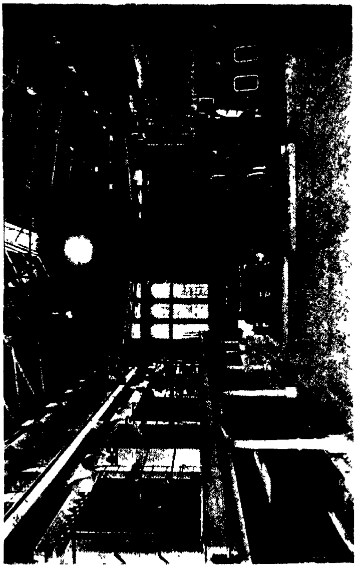


Fig. 5. *Interior of Engine-House, looking East.*

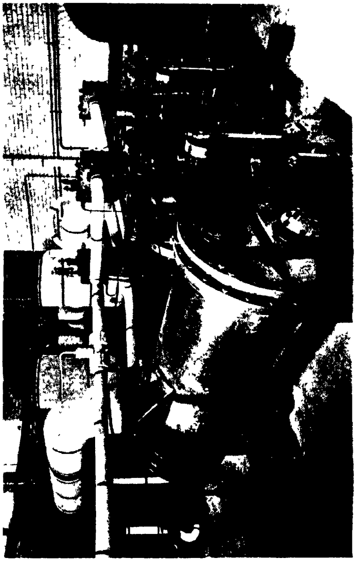


Fig. 4. *Condensing Plant.*

ROTHESAY DOCK.

Fig. 7. *General View of Generating Station and Coal-Hoists 1 and 2.*

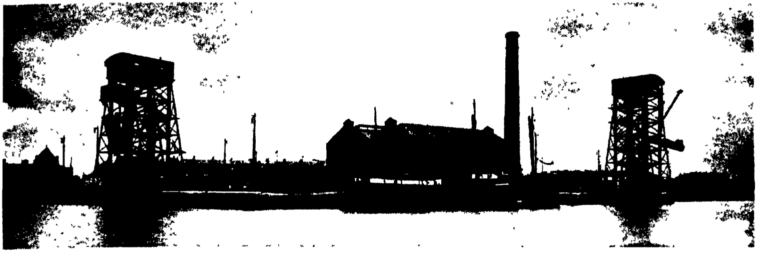
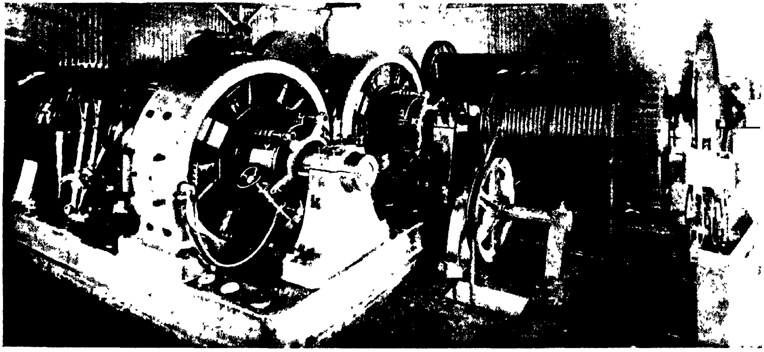


Fig. 8. *Interior of Attendant's Cabin near top of Hoist.*

Fig. 9. *Hoisting and Tipping Machinery at top of Hoist*



ROTHESAY DOCK.

Fig. 10. *General View at No. 1. 32-ton Coal-Hoist, Lift 50 ft.*

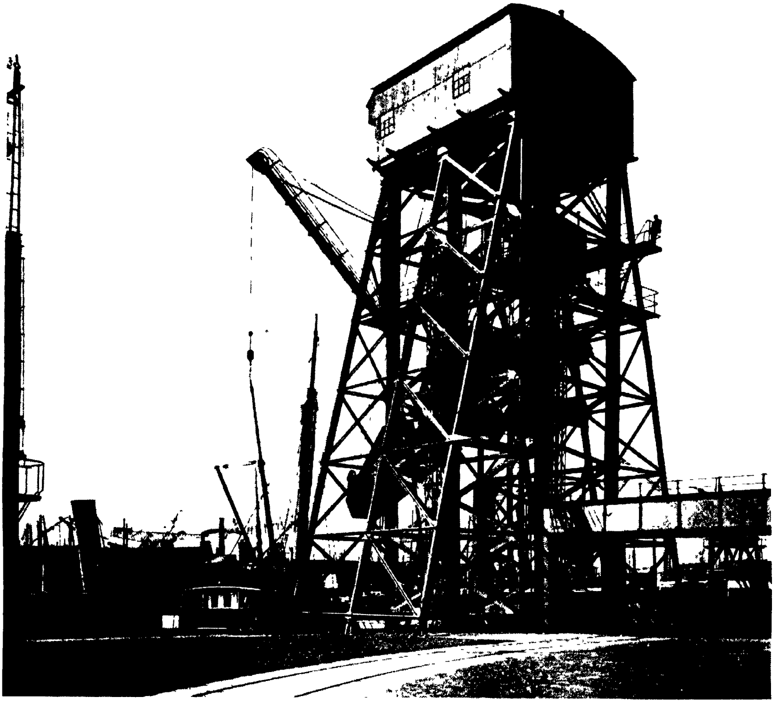


Fig. 12. *Turntable in tipping position.*

ELECTRICAL DOCK-EQUIPMENT.

Plate 4.

ROTHESAY DOCK.

Fig. 14. *4-ton Jib Crane. Lift 80 ft. Radius 20-45 ft.*

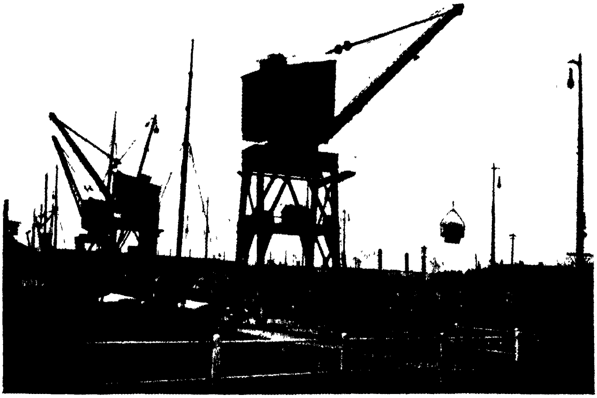


Fig. 17. *Cable Subway.*

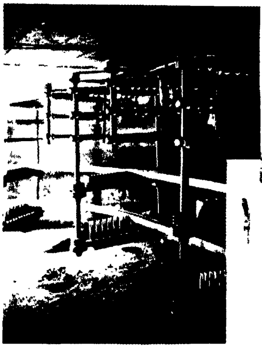


Fig. 18.
Pier-head Capstan and its Control House.

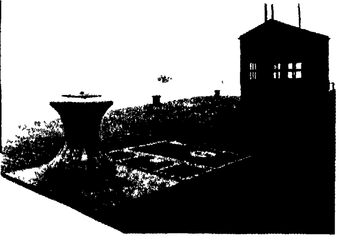


Fig. 19.
Internal arrangement of "Clyde" Capstan.

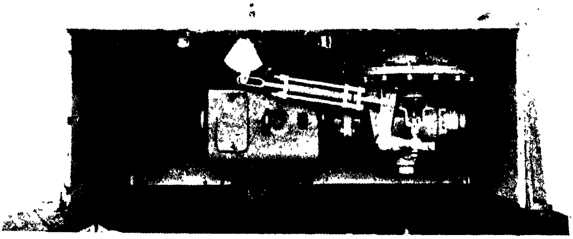


Plate 5.

STEEL.

Fig. 10. 1·76% C Steel Quenched at 1,120° C. (2,048° F.) × 200 diams.

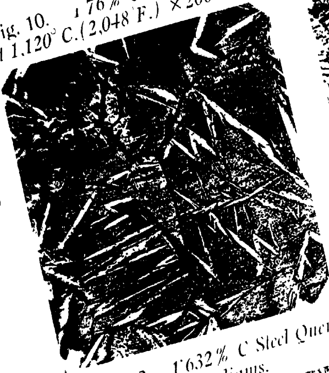


Fig. 11. 1·76% C Steel Quenched, at 1,170° C. (2,138° F.) × 200 diams.

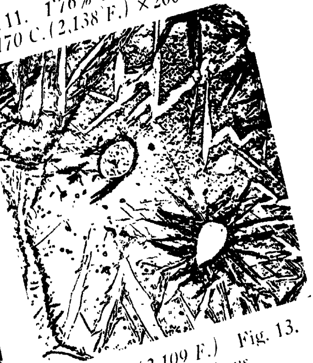


Fig. 12. 1·632% C Steel Quenched at 1,154° C. (2,109° F.) Fig. 13.

Fig. 12. × 150 diams.

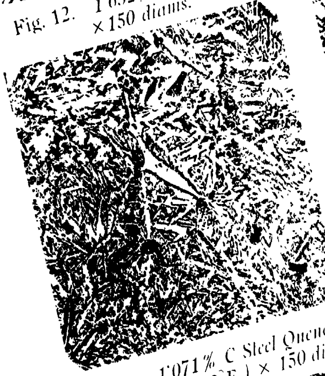


Fig. 13. × 800 diams.

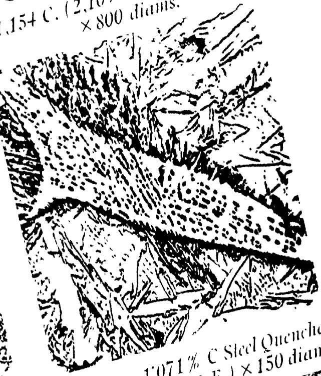


Fig. 14. 1·071% C Steel Quenched at 1,128° C. (2,062° F.) × 150 diams.

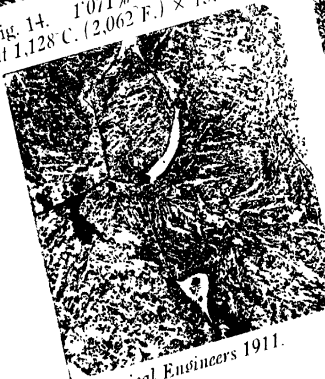
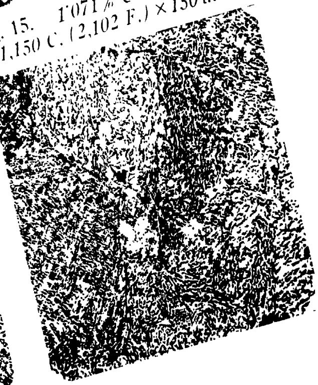


Fig. 15. 1·071% C Steel Quenched at 1,150° C. (2,102° F.) × 150 diams.



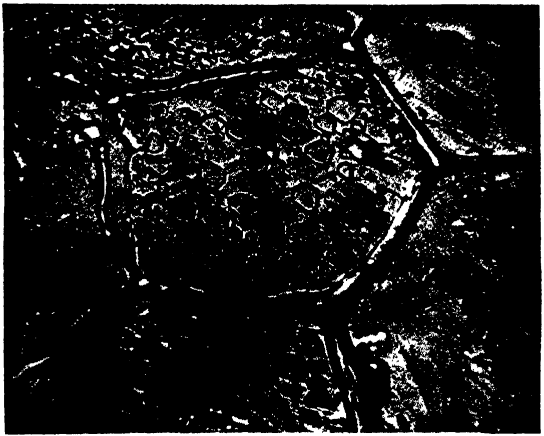
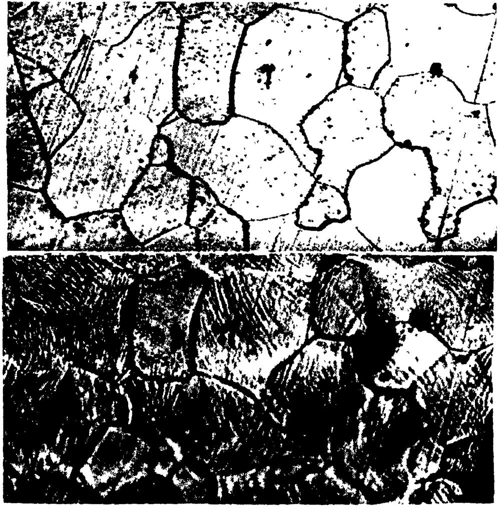


Fig. 25.
Pits formed by air-bubbles in a surface of Cadmium cast against glass, showing the geometrical orientation of Crystalline elements.
× *1,000 diams.*



Figs. 27 and 28.
The same area in a specimen of nearly pure Iron, as seen before and after plastic strain.
× *200 diams.*

Fig. 29.
Slip-bands in Iron.
× *500 diams.*

Fig. 30. *Slip-bands in Lead.* × *1,000 diams.*

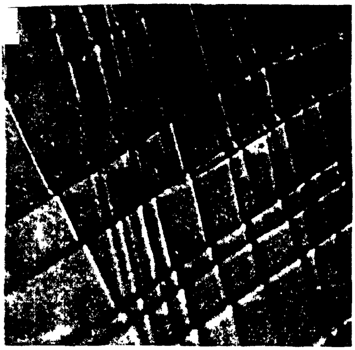


Fig. 31. *Slip-bands in 25% Nickel-Steel.* × *200 diams.*

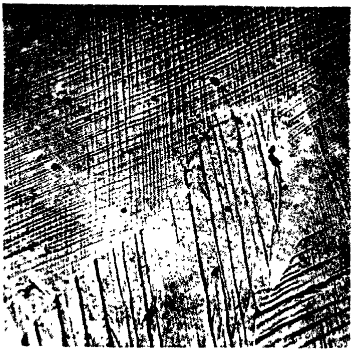


Fig. 32. *Slip-bands in Copper, showing twinning.* × *1,000 diams.*

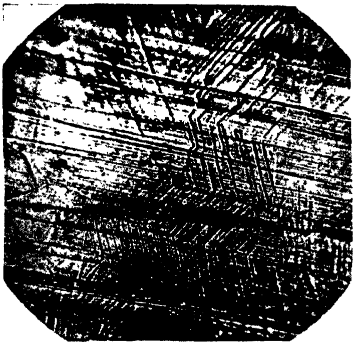


Fig. 34. *Heat-tinting effect on polished Iron. Heated in vacuo.* × *500 diams.*

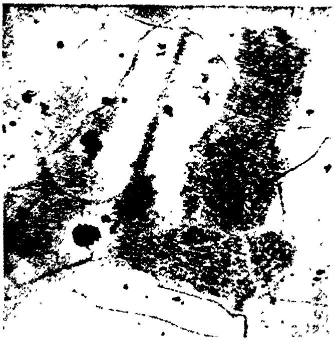


Fig. 35. *Allotropic change shown by slip-bands.* × *100 diams.*

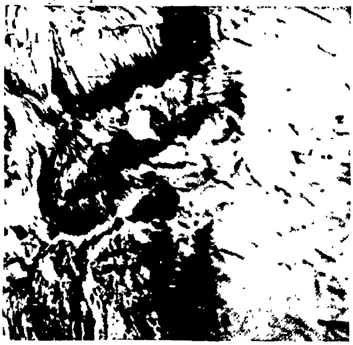


Fig. 36. *Slip-bands in hot γ-iron showing twinning.* × *150 diam*

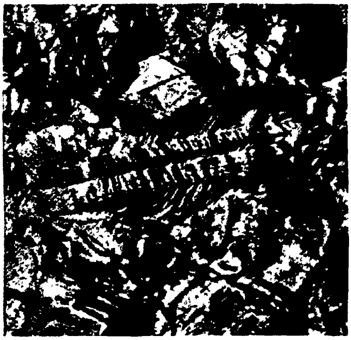


Fig. 37. *Allotropic change in Electrolytic Iron shown by slip-bands. × 100 diams.*

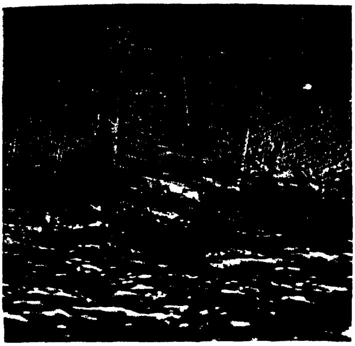


Fig. 38. *Slip-bands and multiple twinning in hot γ-iron (Electrolytic Iron). × 100 diams.*

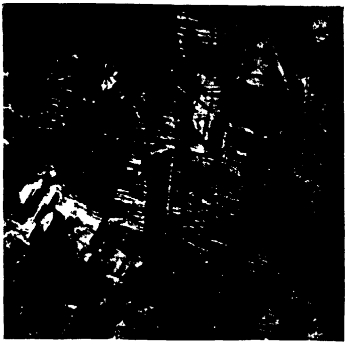


Fig. 39. *Multiple twinned structure, characteristic of Brass. × 250 diams.*

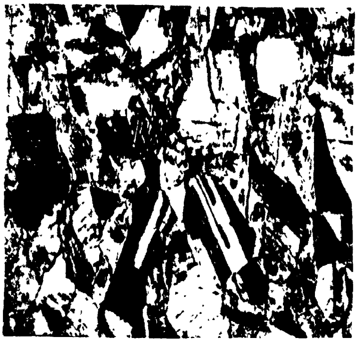


Fig. 41. *Steel containing 0·07 % Carbon. × 500 diams.*

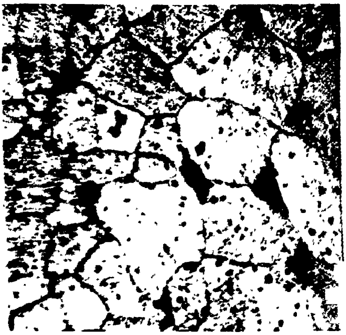


Fig. 42. *Steel containing 0·18 % C showing a Carbon-free band. × 500 diams.*

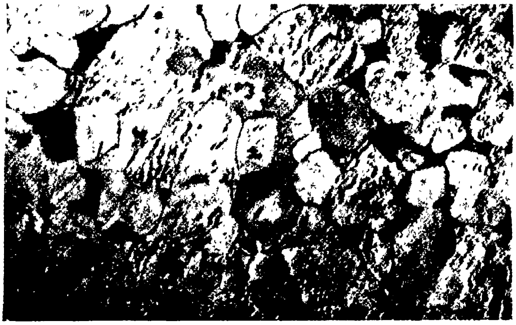


Fig. 43. *Steel with 0·43% Carbon. × 500 diams.*

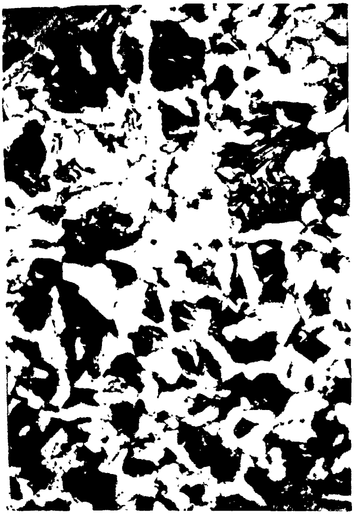


Fig. 44. *Steel with 0·43% C after prolonged annealing. × 500 d.*

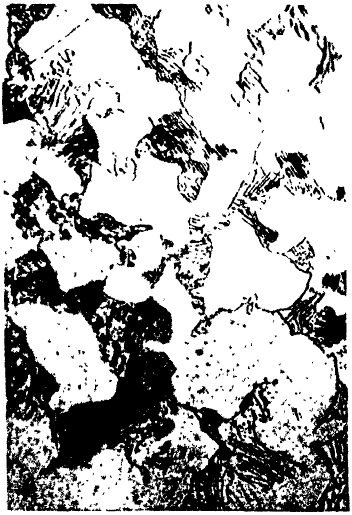


Fig. 45. *Banded Structure of rolled Steel. × 100 diams.*

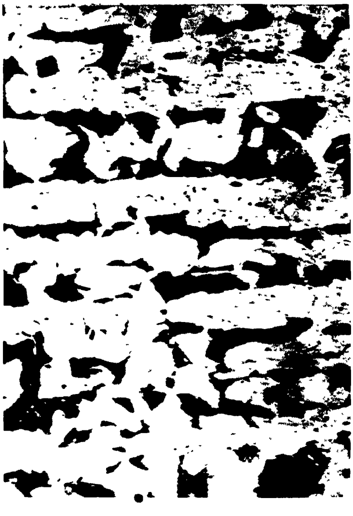
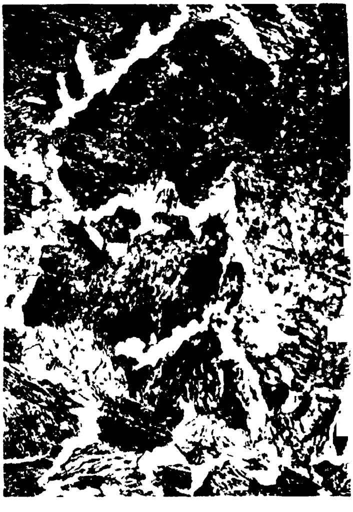


Fig. 46. *Steel with 0·6% Carbon. × 300*



STEEL.

Fig. 47. *Steel with 0·8 % Carbon.*
× *500 diams.*

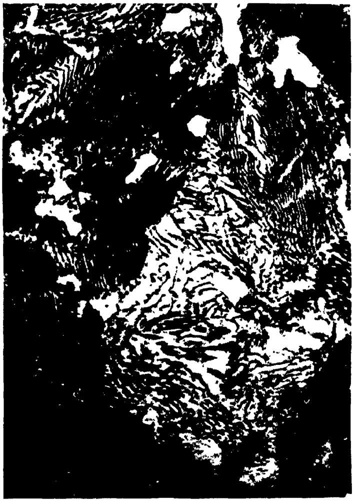


Fig. 48. *Alloy of Copper and Silver, showing crystals of Silver embedded in eutectic.* × *100 diams.*

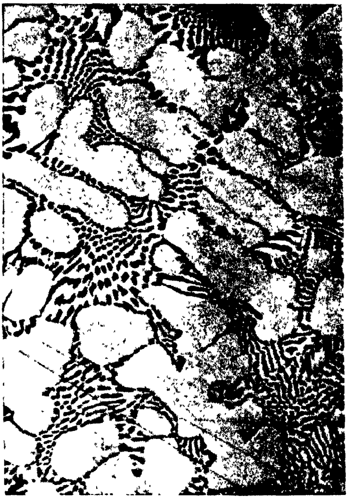
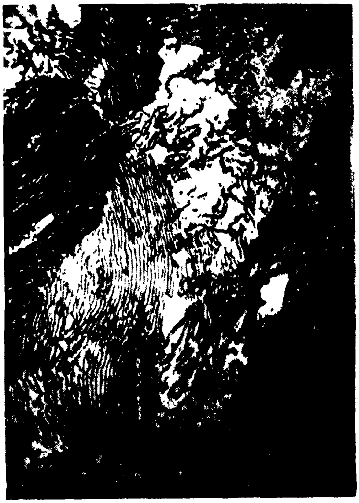
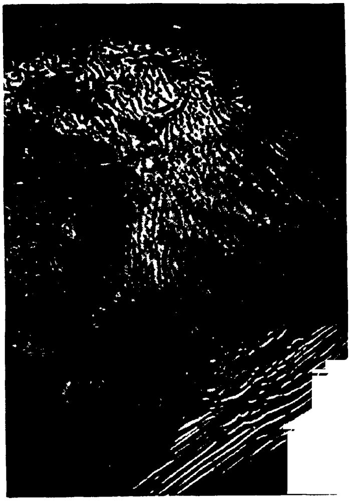


Fig. 49. *Typical examples of "Pearlite."* Fig. 50.

× *500 diams.*



× *1,000 diams.*



g. 51. *Eutectic Alloy of Lead and Tin.* × *150 diams.*

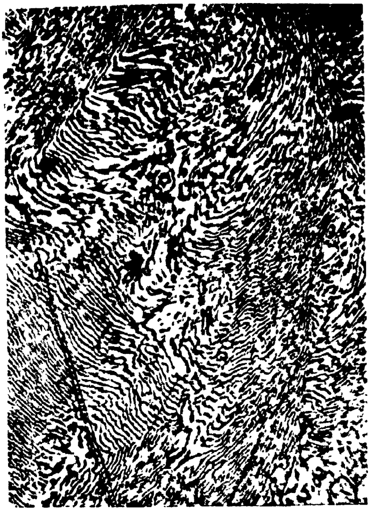
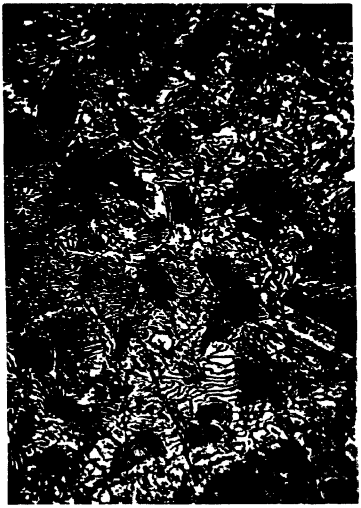


Fig. 52. *Steel with 1·2% C, showing free "Cementite."* ×*500 d.*



Steel with 2·2% Carbon.

Fig. 53. *As Forged.* × *300 diams.*

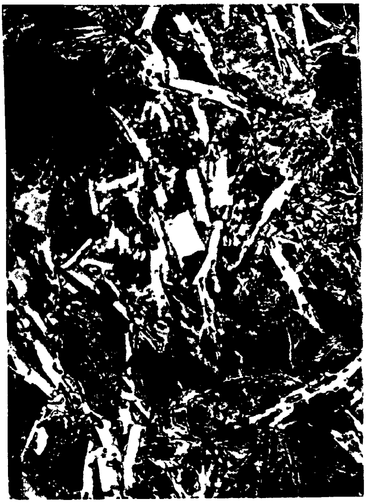
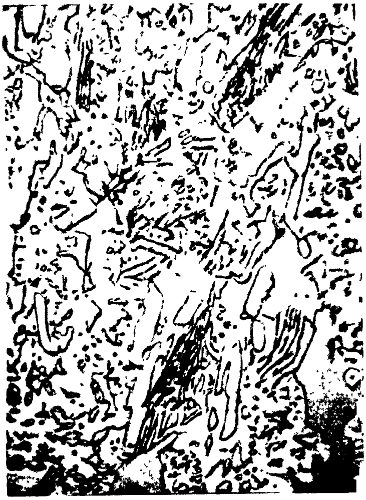
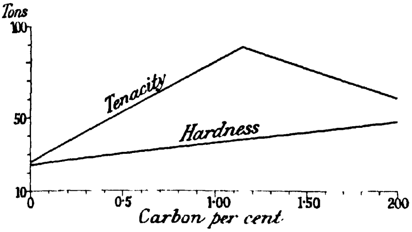


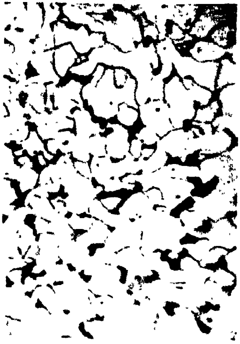
Fig. 54. *Annealed.* × *500 dia*

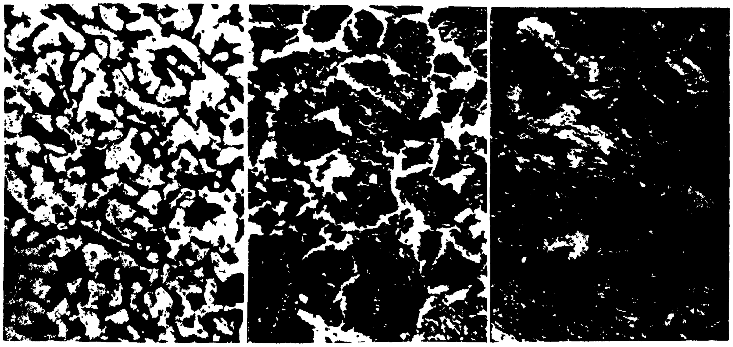


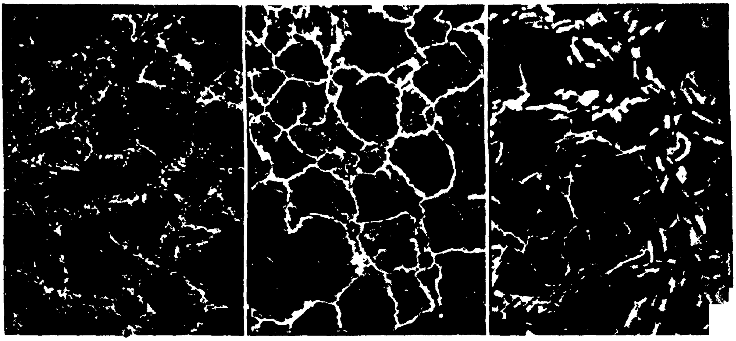
Mechanical Engineers 1911.

Fig. 55. *Diagram showing connection between Constitution, Micro structure and Mechanical Properties.* × *150 diams.*




0'095 % C.


0'326 % C. *0'642 % C.* *0'991 % C.*


1'263 % C. *1'425 % C.* *1'972 % C.*

Mechanical Engineers 1911.

Fig. 56. *Fracture of nearly pure Iron in Tension.* × *800 diams.*

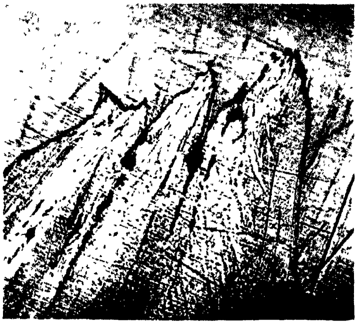


Fig. 57. *Tensile Fracture of Mild-Steel.* × *150 diams.*

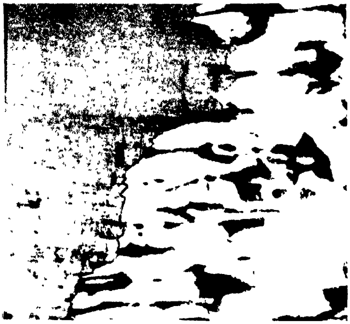


Fig. 58. *Tensile Fracture of Mild-Steel, showing the rupture of Pearlite Grains.* × *1,200 diams.*

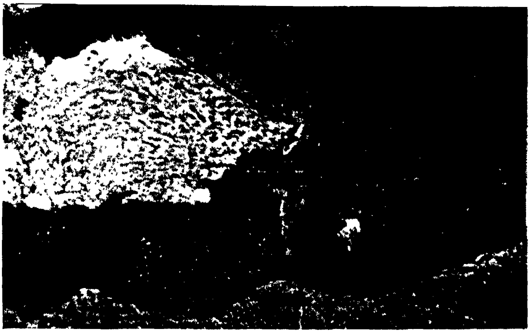


Fig. 59. *Shock-fracture of Wrought-Iron.* × *100 diams.*

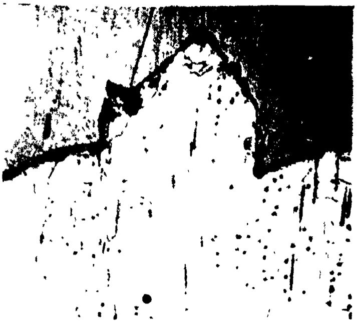
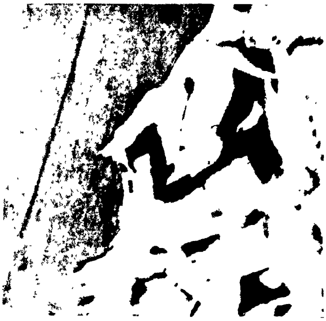


Fig. 60. *Shock-fracture of Mild-Steel.* × *800 diams.*



Mechanical Engineers 1911.

STEEL.

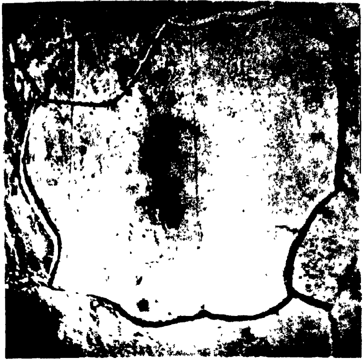


Fig. 61. *Specimen of Swedish Iron after 1,000 reversals of a stress of 12·4 tons per sq. in.* × *500 diams.*

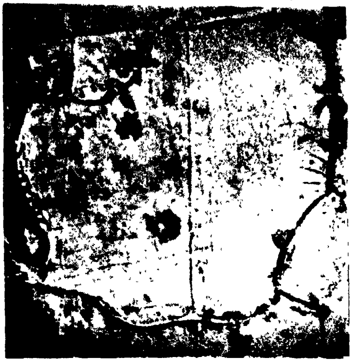


Fig. 62. *The same after 2,000 reversals.* × *500 diams.*

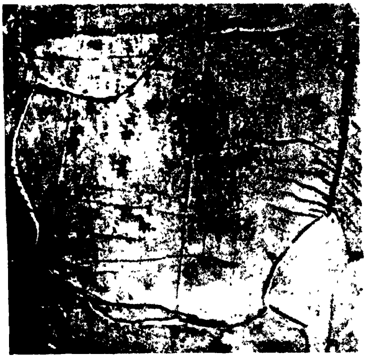


Fig. 63. *The same after 10,000 reversals.* × *500 diams.*

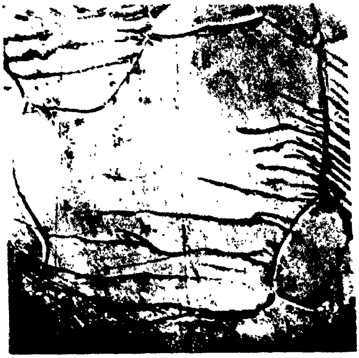


Fig. 64. *The same after 40,000 reversals.* × *500 diams.*

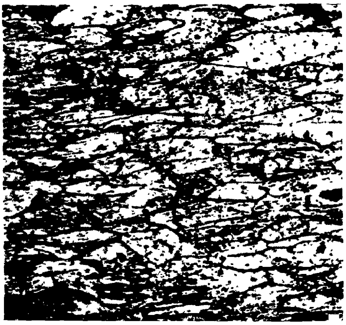


Fig. 65. *Ferrite after severe plastic deformation.* × *100 diams.*

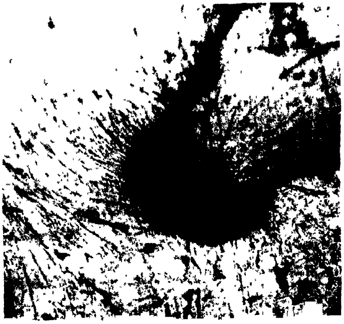


Fig. 66. *Section through the "root" of a heavy cut taken in a lathe on Mild-Steel. Shows the crushing action of the tool.* × *100 diams.*

Mechanical Engineers 1911.

Fig. 67. *Mechanically deformed Pearlitic-Steel.* × *100 diams.*

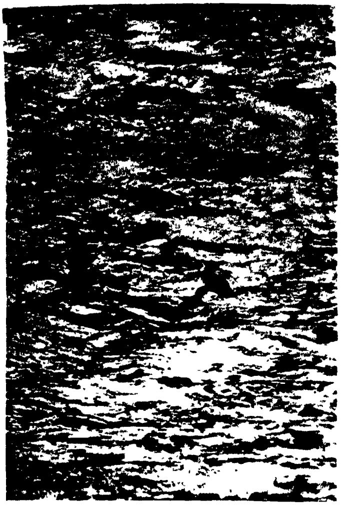


Fig. 68. *Structure of Mild-Steel, which has been heated to 1,000° C. (1,832° F.) at one end. Full size.*

Fig. 69. *Over-heated and partially decarburized Steel.* × *150 diams.*

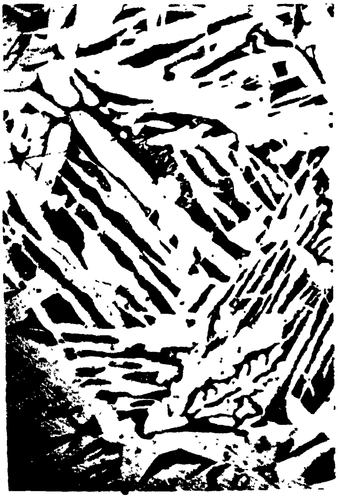
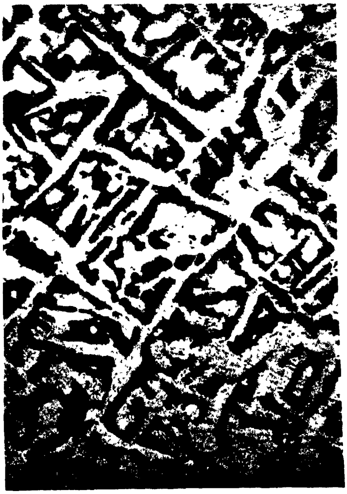


Fig. 70. *Over-heated Mild-Steel.* × *150 diams.*



Boiler-Plate damaged by Heat-Treatment.

Fig. 71. *Etched with Sodium Picrate, showing veins of Cementite.* × *750 diams.*

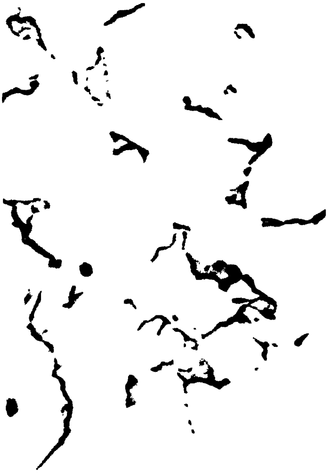


Fig. 72. *Cracks in the Plate.* × *500 diams.*

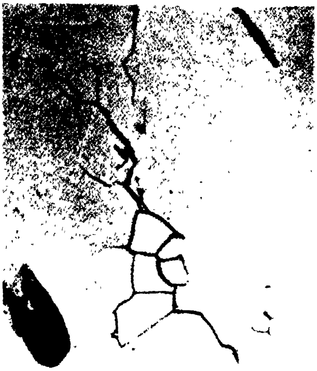


Fig. 73. *Cracks following Crystal boundaries.* × *750 diams.*

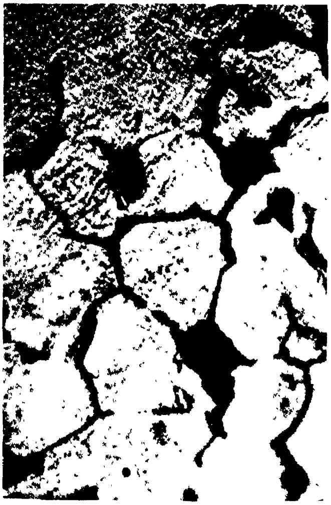


Fig. 74. *Shock-fracture showing inter-crystalline weakness.* × *20(*

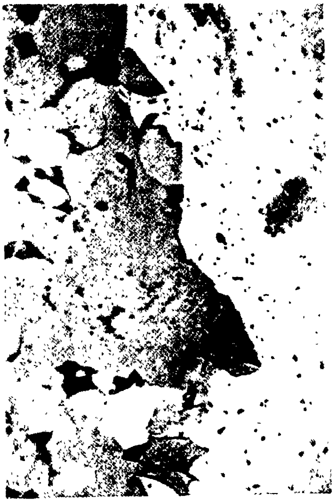


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Fig. 75. *Austenitic or Gamma-Iron Nickel-Steel.* × *200 d.*

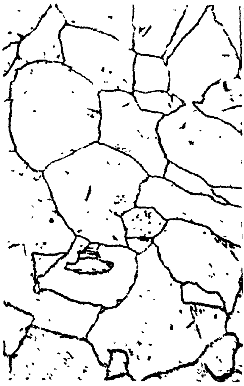


Fig. 76. *Quenched 2 % Manganese-Steel.* × *200 diams.*

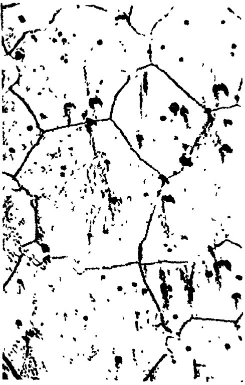


Fig. 77. *Steel with 2 % C etched at 1,100° C. with HCl Acid Gas.* × *200 d.*

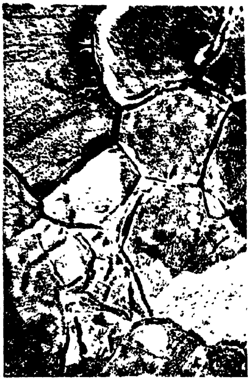


Fig. 78. *Same specimen as Fig. 77, more highly magnified.* × *530 diams.*

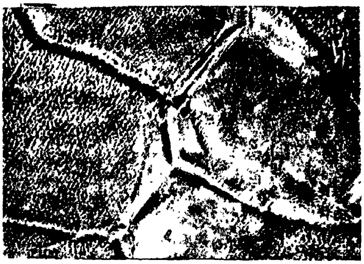


Fig. 79. *Steel with 0·12 % C etched at 1,100° C. (2,012° F.)* × *200 diams.*

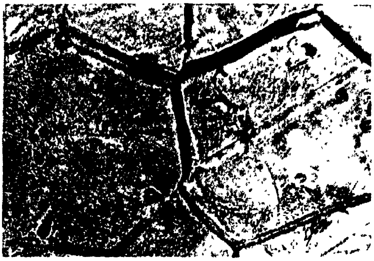


Fig. 80. *Twinning in Gamma-Iron, etched at 1,000° C. (1,832° F.)* × *530 diams.*

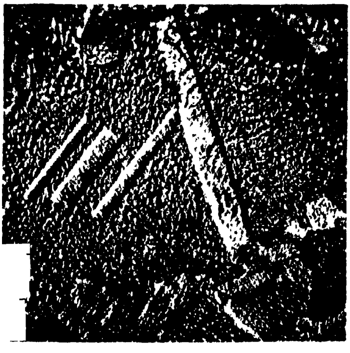


Fig. 81. *Transformation products in strained Austenitic Nickel-Steel.* × *200 diams.*

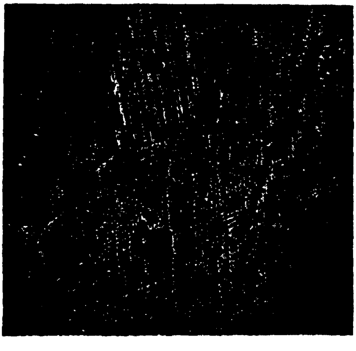


Fig. 82. *Steel with 2% Carbon, Quenched at 1,000° C. (1,832° F.)*
× *150 diams.*

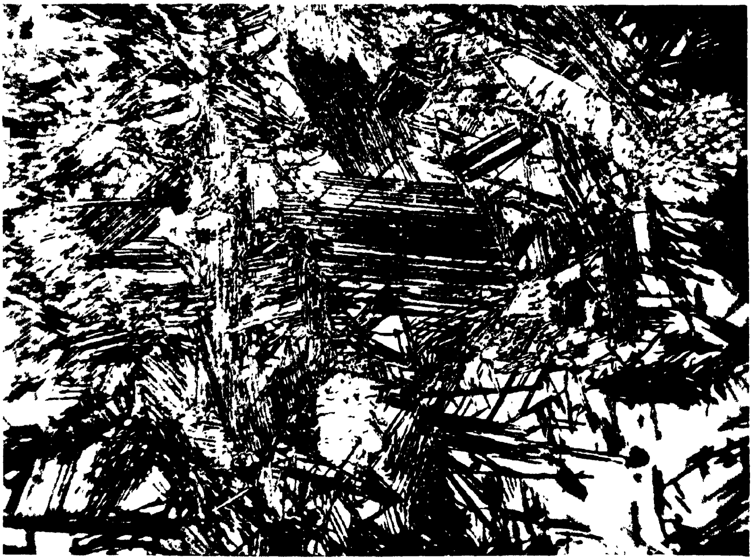


Fig. 83. *2% Carbon-Steel,*
Quenched at 1,000° C. (1,832° F.)
Showing twinning. × *500 diams.*

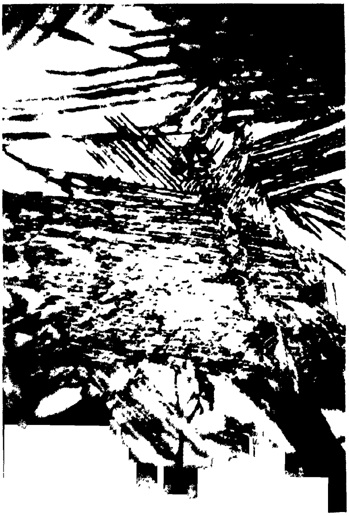
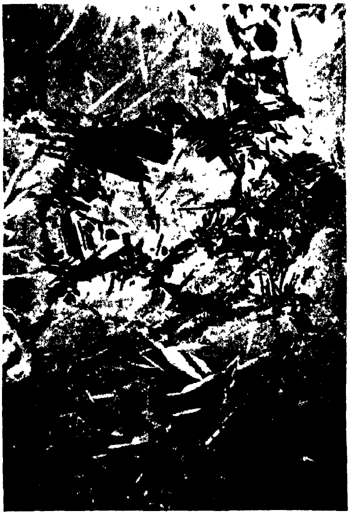


Fig. 84. *Austenite and Martensite*
in Quenched 2% C Steel.
× *100* "



STEEL.

Fig. 85. *Austenite and Martensite in Quenched Steel.* × *150 diams.*

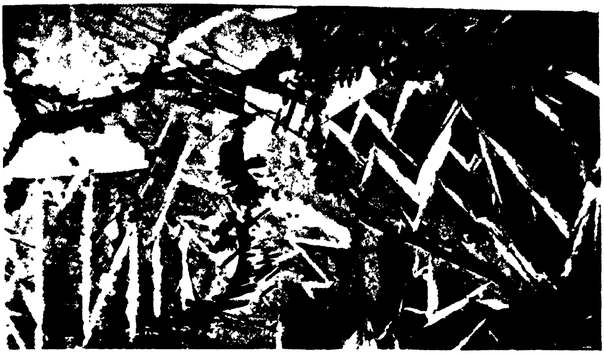


Fig. 86. *Typical Martensite Structure.* × *500 diams.*

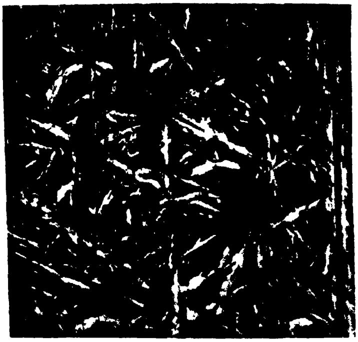
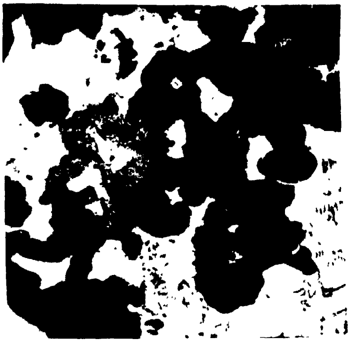


Fig. 87. *Troostite and Martensite.* × *300 diams.*



88. *Martensite, Troostite and Pearlite.* × *800 diams.*

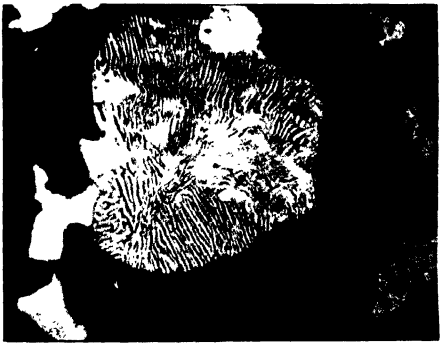


Fig. 89. *Pearlitic constituent formed by the decomposition of the compound $Al_2 Zn_3$ in Al Zn alloys.* × *600 diams.*

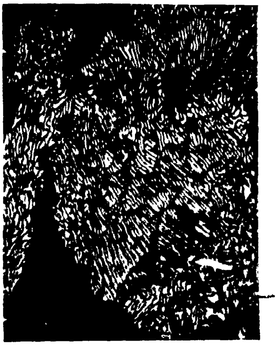


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Plate 2

Parts of Two Bronze Force-Pumps, Bolsena, Etruria.

Constructed on the principle invented third century B.C., by Ctesibius of Alexandria.